火灾科学国家重点实验室
STATE KEY LABORATORY OF FIRE SCIENCE

公共安全研究中心
CENTER FOR PUBLIC SAFETY RESEARCH

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Progress of Fire and Emrgency Management Research in China

Weicheng FAN[1,2] and Nai'an LIU[1]

State Key Laboratory of Fire Science, USTC[1]

Center for Public Safety Research, THU[2]

Background:

Fire safety situation : Severe

Fire safety problems: One of the major concerns for public and government

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In 2002, the PROJECT "Fire Dynamics and Fundamentals of Fire Protection" was promoted

→ Gain deep understanding of natural fire phenomena and whereby facilitate the development of fire safety technologies.

PROJECT---- Research Topics

①Fire Formation and its Propagation

②Generation and Release of Fire Smoke and Its Toxicity

Fire Dynamic Theory

③Fire Risk Assessment and Performance-based Design based on Fire Dynamics and Statistical Theory

④High Quality Fire Retardant Materials

⑤Intelligent and Reliable Recognition of Fire Signals for Detection Technology

⑥Clean Fire Suppression Technology with High Efficiency

Principle of Fire Protection Technology

PROJECT

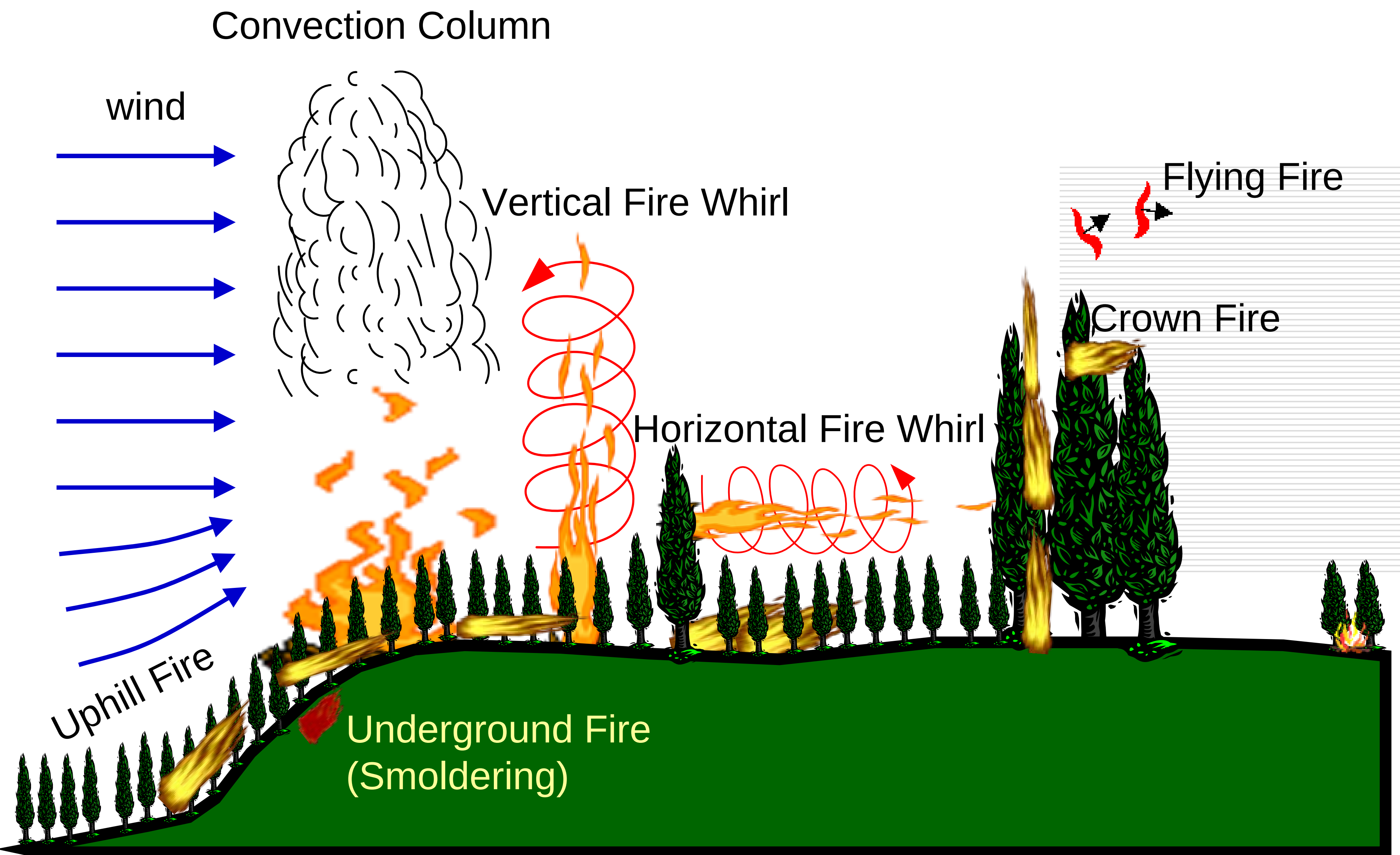
① (a) Fire Formation and Its Propagation

Fire Formation Mechanism——

- Pyrolysis Model of Combustibles Under Different Conditions
- Ignition Models of Combustibles
- Mechanism of Smoldering and its Transition to Flame

How to construct——

Decision Making System for Forest Fire Protection



How to construct——
Decision Making System for Forest Fire Protection

Fire Dynamical Model
+
Environmental Conditions

- Fire Propagation Speed
- Fire Intensity

Making Decision

Fire Formation----
Decomposition Kinetics of Solid Combustibles

W

eva

$$\frac{\mathrm{d}x}{\mathrm{d}T} = \frac{A}{\beta}\exp\left(\frac{-E_a}{RT}\right)[f(x)]^n.$$

The independent pseudo bi-component model [23] is
loss of the API separator sludge:

Cited by **Journal of Analytical and Applied Pyrolysis**

"Two-stage Gaussian Smoothing Strategy" for biomass decomposition data pre-treatment

Liu N. A.; Chen H. X.; Shu L. F. ***Industrial & Engineering Chemical Research*****,** 2004。Referee's comment:：It should be a relevant contribution for a solid numerical analysis of the experimental data, improving the data handling and being more precise with the criteria used to determine the 'best' kinetic parameters that reproduce the experimental results.)

$$dT \quad m_{10} - m_{2\infty} \quad dT$$

$$k_i(T) = A_i \exp(-E_i/RT)$$

Fire Formation----
Secondary reactions in particle wood decomposition

A **single particle pyrolysis model** is presented, which

- involves the kinetic sub-model of **secondary reactions** of primary pyrolytic product
- includes the processes of the **yielding, consuming, accumulating or escaping** of the major pyrolysis products in developing porous matrix of reacting wood.
- is capable of simulating the complex pyrolysis process in enough detail

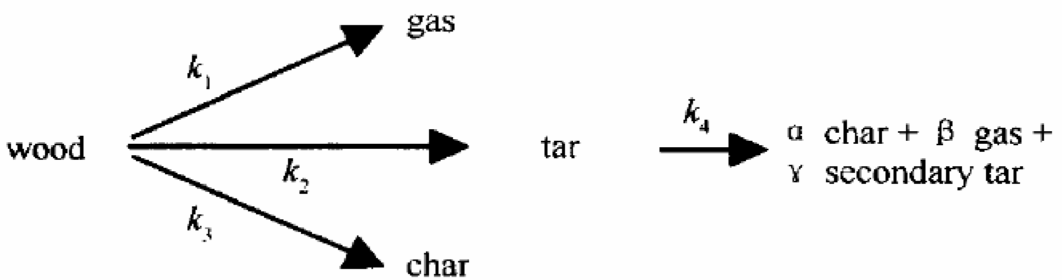
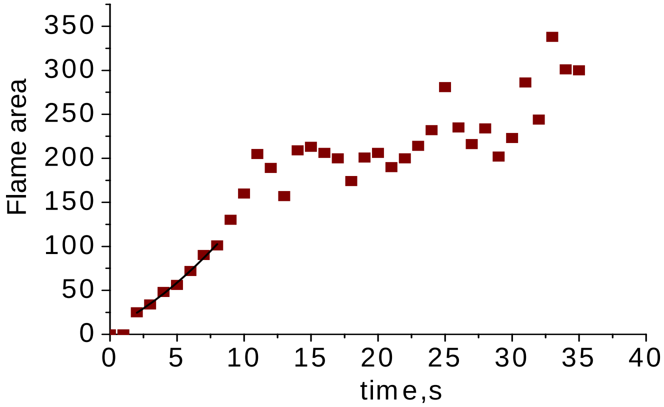


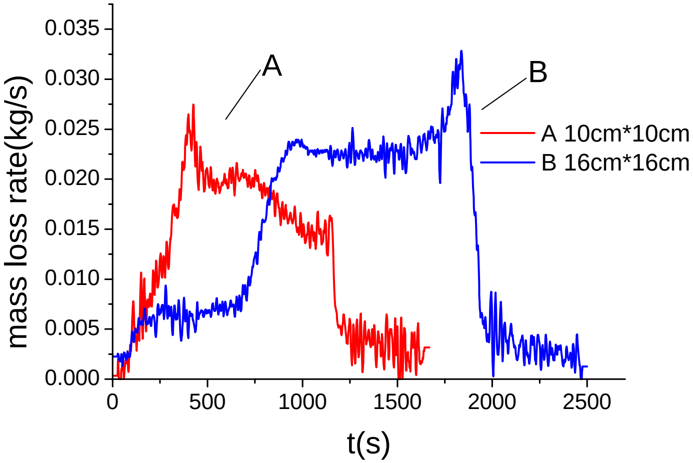
Figure Kinetic model of wood pyrolysis

Fire Formation---- Characteristics of early-stage fire

Developed an experimental system to study the characteristics of early-stage fire, such as pyrolysis / ignition behavior and smoke generation



Flame area vs time

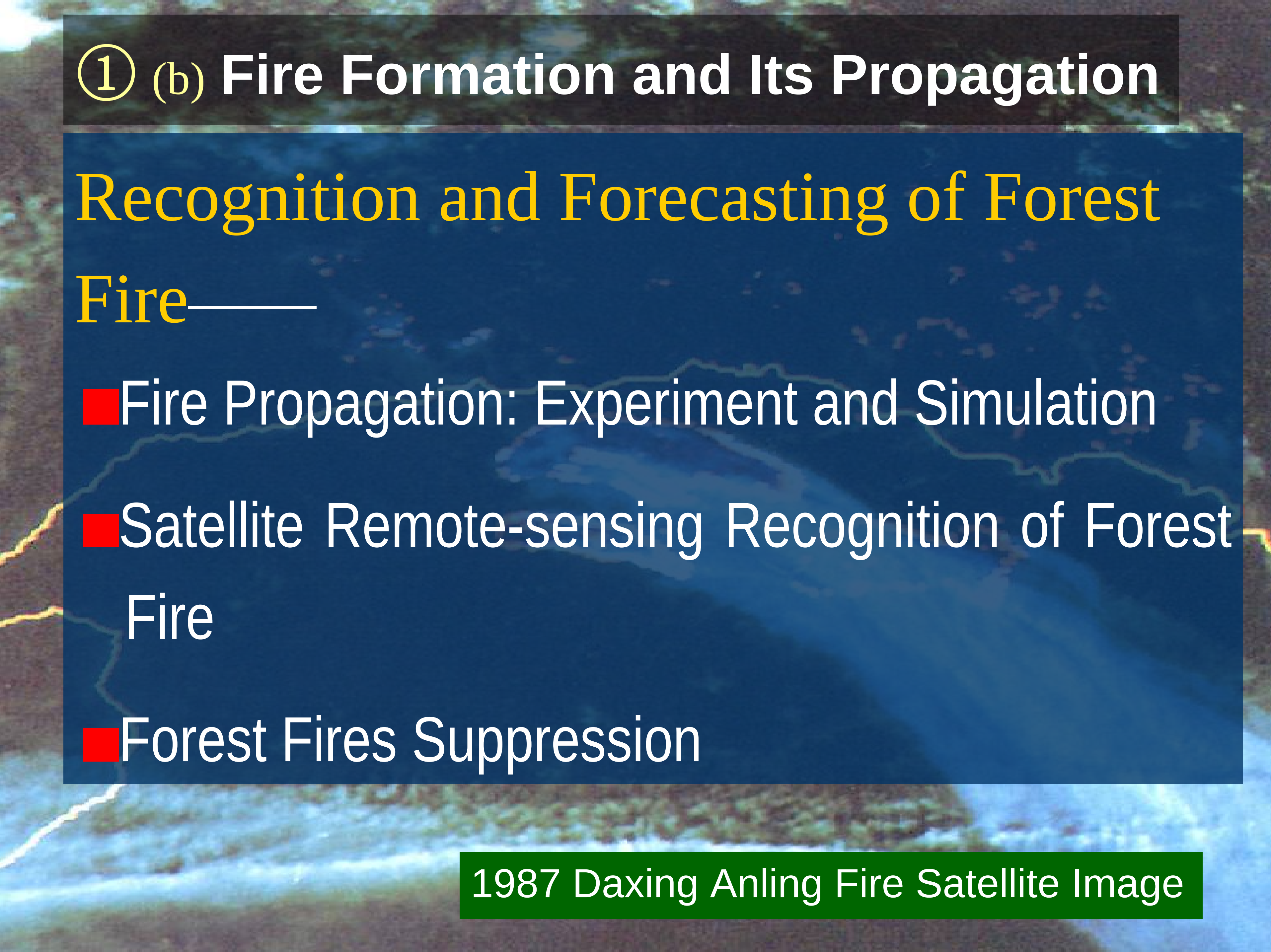


The effect of sample size on the mass loss rate

① (b) Fire Formation and Its Propagation

Recognition and Forecasting of Forest Fire——

- Fire Propagation: Experiment and Simulation
- Satellite Remote-sensing Recognition of Forest Fire
- Forest Fires Suppression



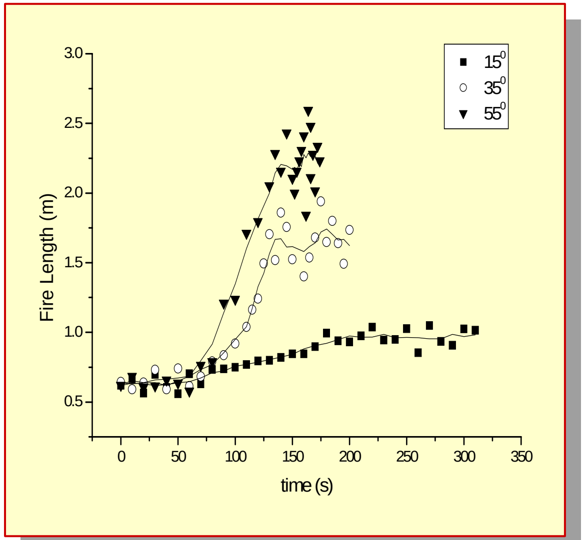
1987 Daxing Anling Fire Satellite Image

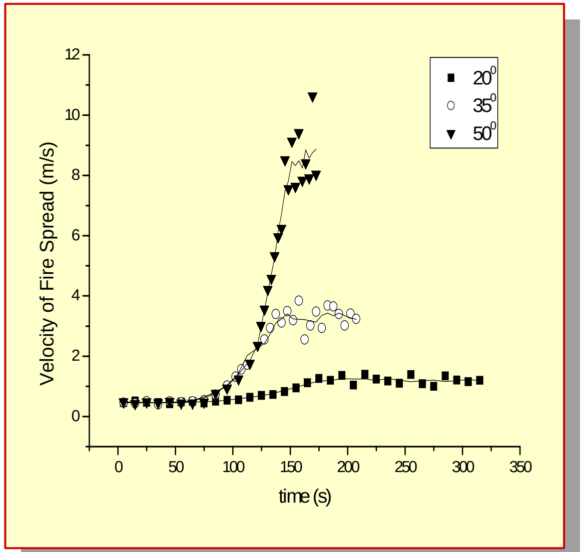
Fire Propagation---- Wind tunnel experiment

- Trace flame automatically
- Heating tubes to adjust the temperature and relative humidity of air inflow
- Involve experimental sector for fire spread experiment with slope

Experimental sector：1.8m(W)× 1.8m(H)× 7.0m(L)

Fire Propagation---- Under Different Slopes

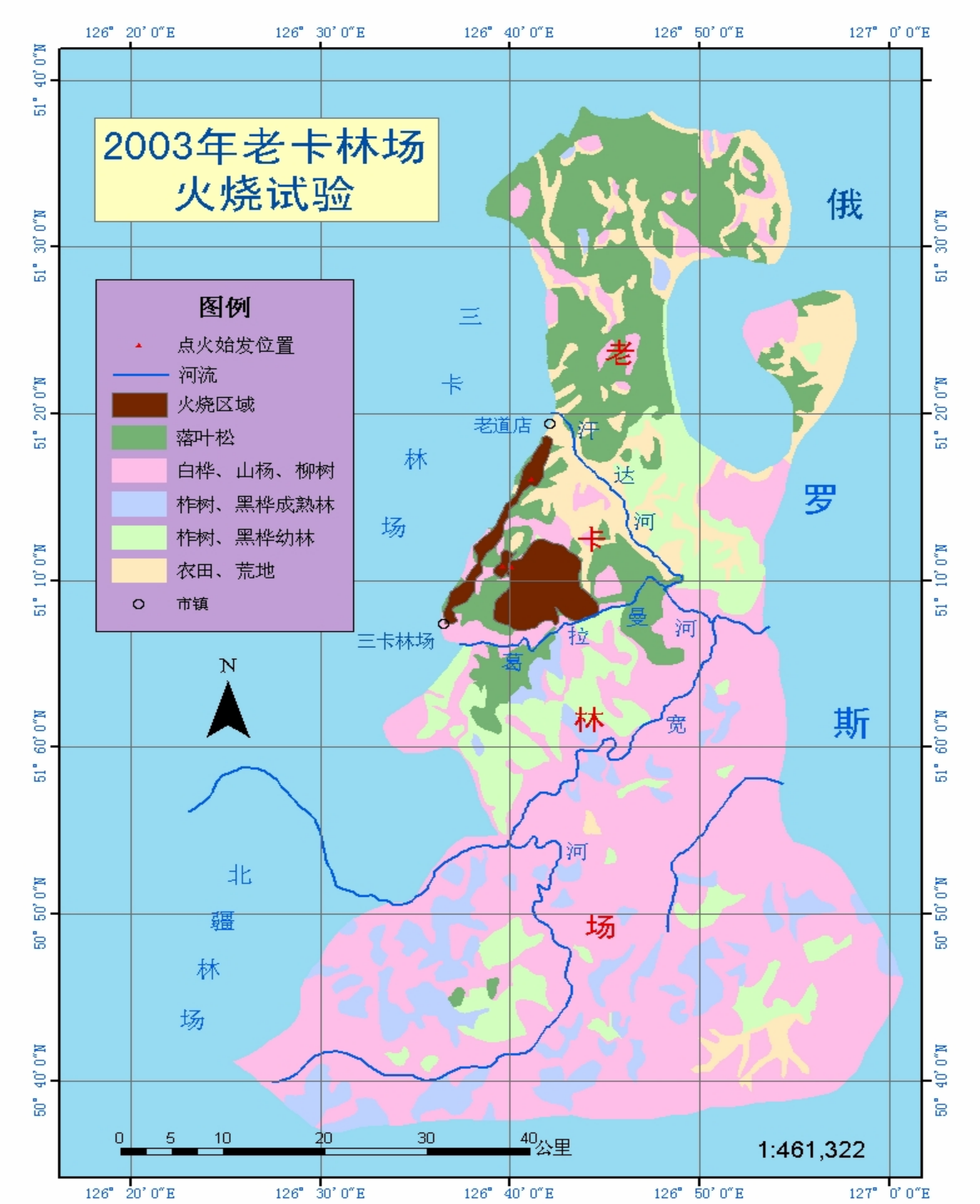




Angle ψ (°)	L_n(m)	L_s(m)	$(1+C_S\beta^{Bs}tg^2(\psi))^{0.46}L_n$(m)	Derivation (%)
15	0.637	0.966	0.901	6.73
20	0.654	1.118	1.046	6.44
30	0.633	1.254	1.362	8.61
35	0.648	1.625	1.666	2.52
45	0.632	1.778	2.127	19.6
50	0.621	1.984	2.421	22.0
55	0.630	2.245	2.890	28.7

- **Fire spread modelling by considering the effect of topography, vegetation and wind speed**

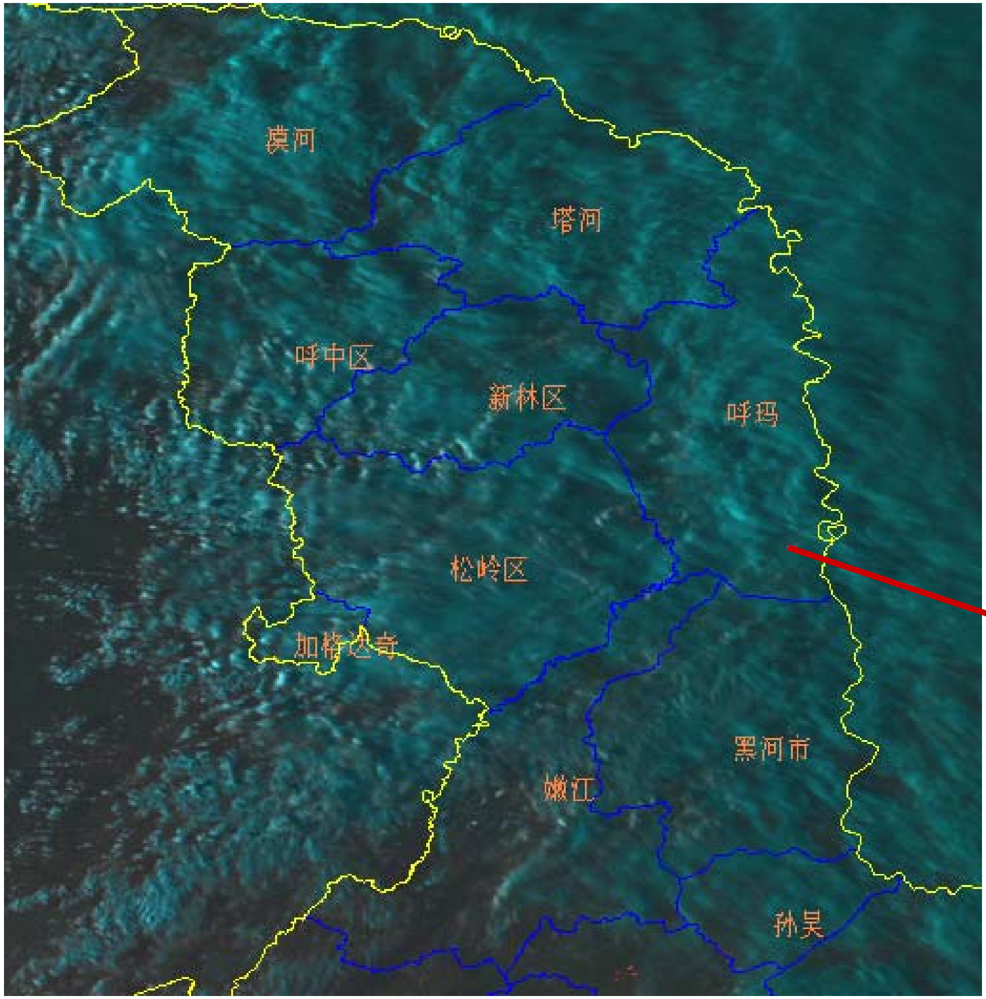
Fire Propagation---- Wildland Fire Experiment

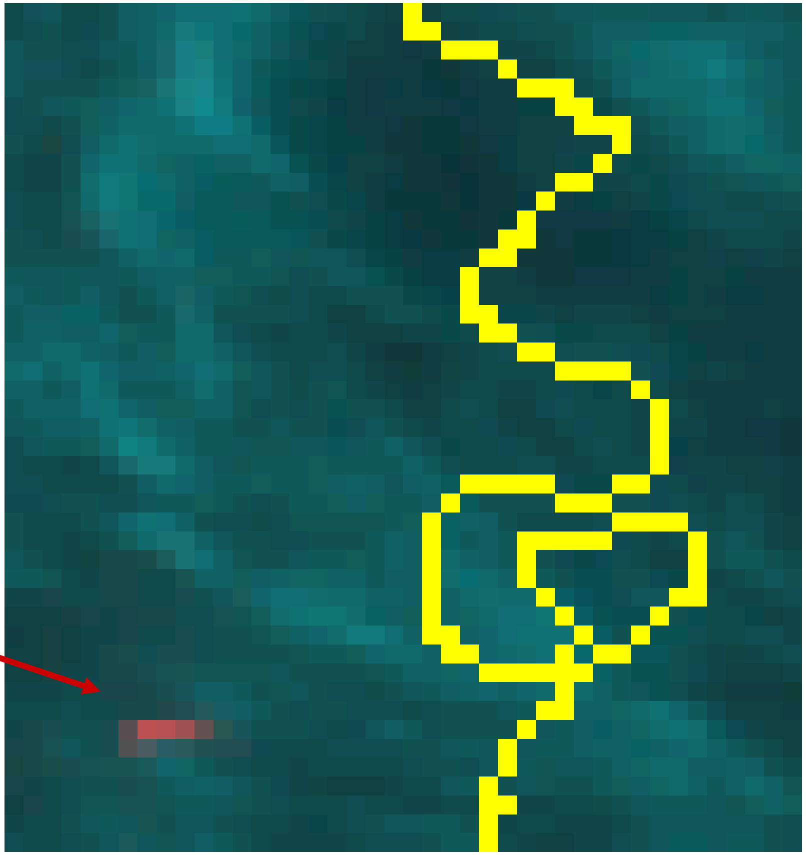


- **Laoka forestry centre, Daxing Anling**
  N 51° 16′ 03″
  E 126° 41′ 09″
- **species: birch、larch 、robur 、grass**

Fuel Investigation

Fire Propagation---- Wildland Fire Experiment by NOAA12 remote sensing





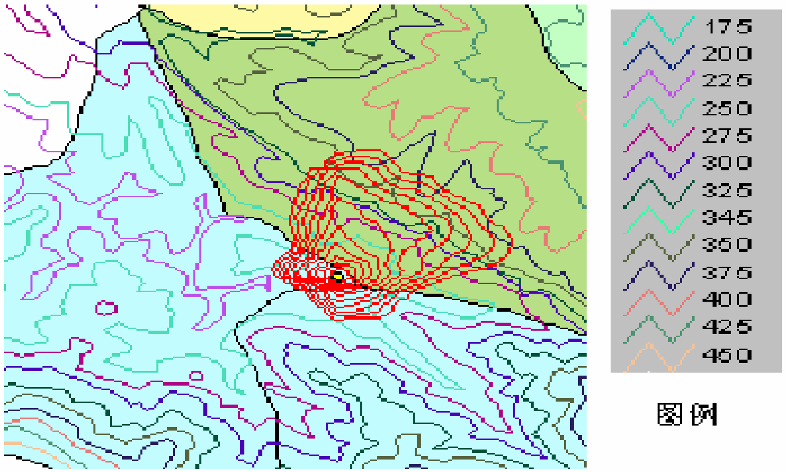
Fire Propagation---- Wind speed: 1.3-2.7m/s; Temperature: 10℃; Humidity: 40%

Broaden the isolation belt

Prescribed burning

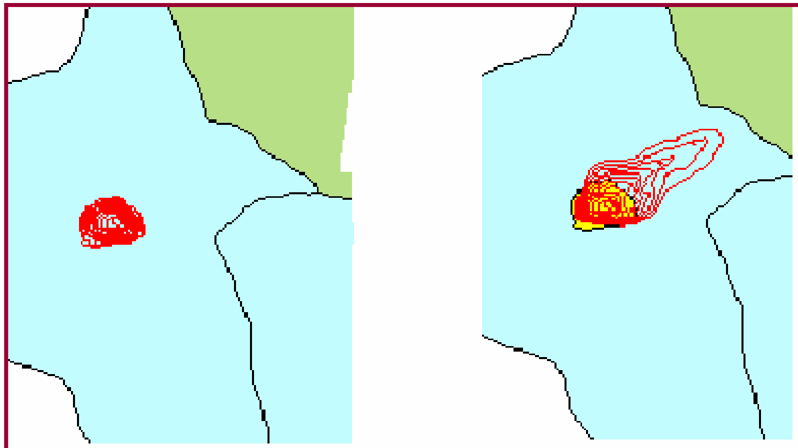
Fire observation

Fire Propagation---- Wind speed and slope corrections in *Decision Making System*



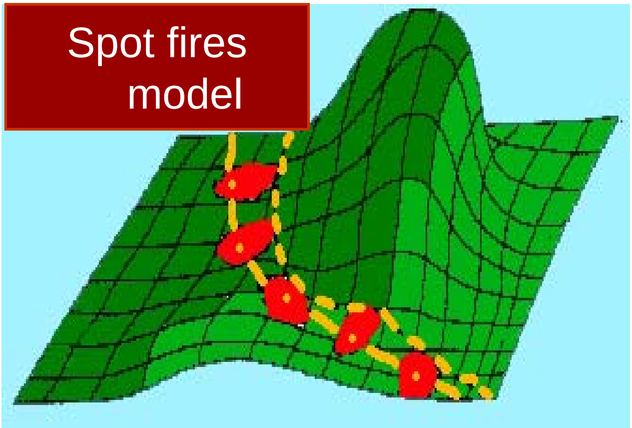
Topography effect

bush massons pine



Wind speed effect

bush massons pine



Prediction of fire behavior

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Intensity of fire front

↓

Suppression mode

↓

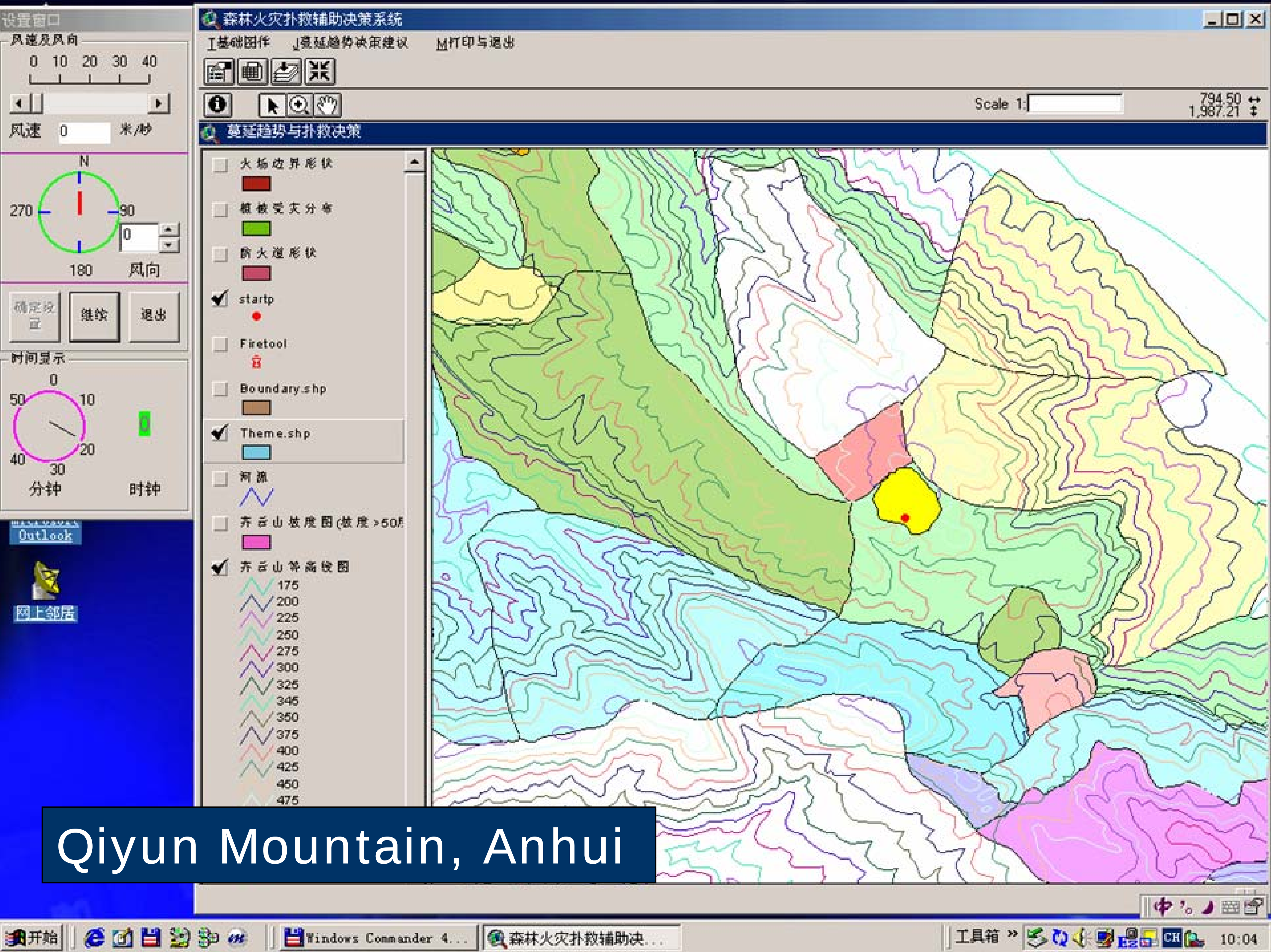
Suppression power （people、tools）

↓

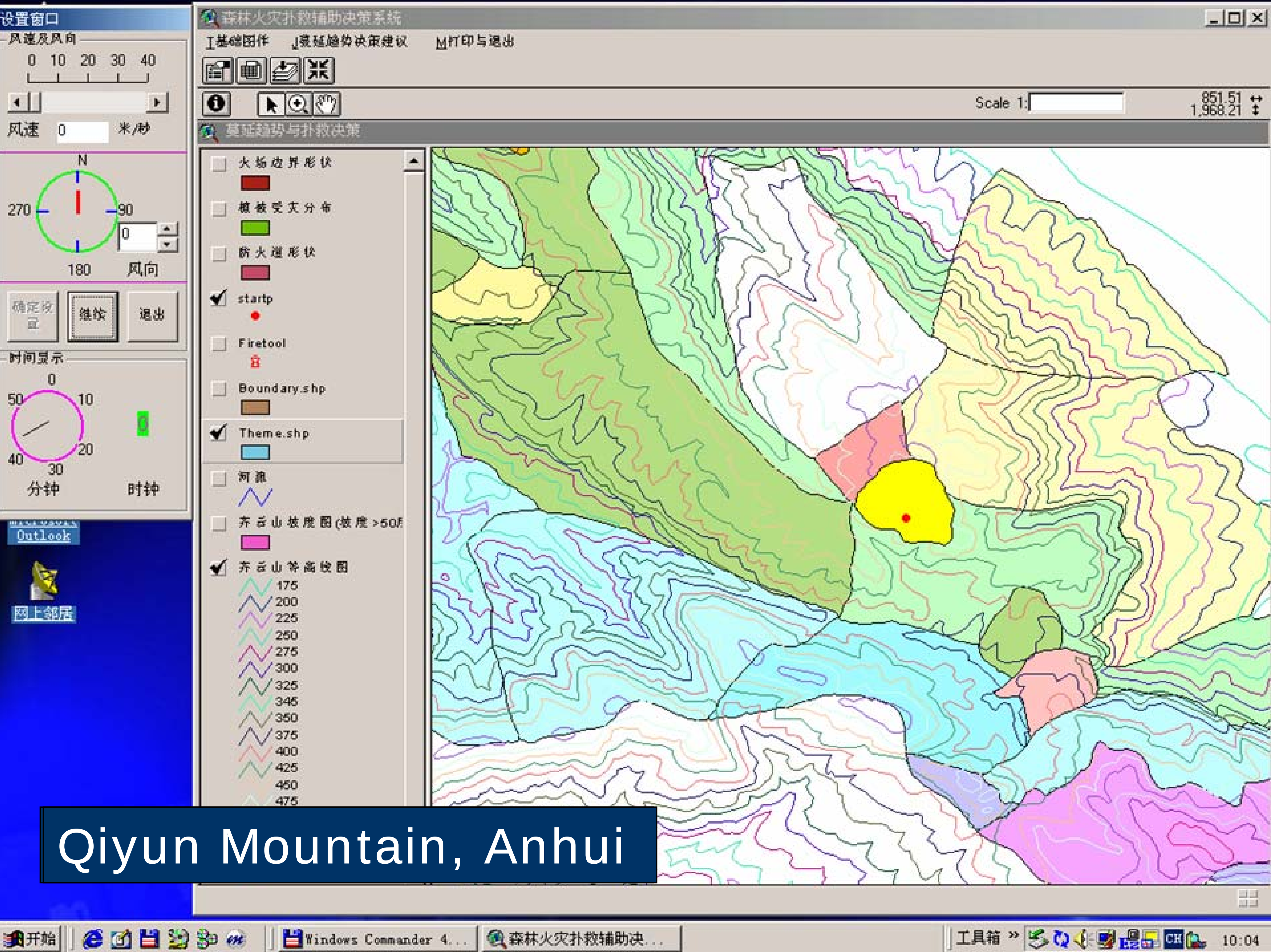
Optimal route ← GIS

↓

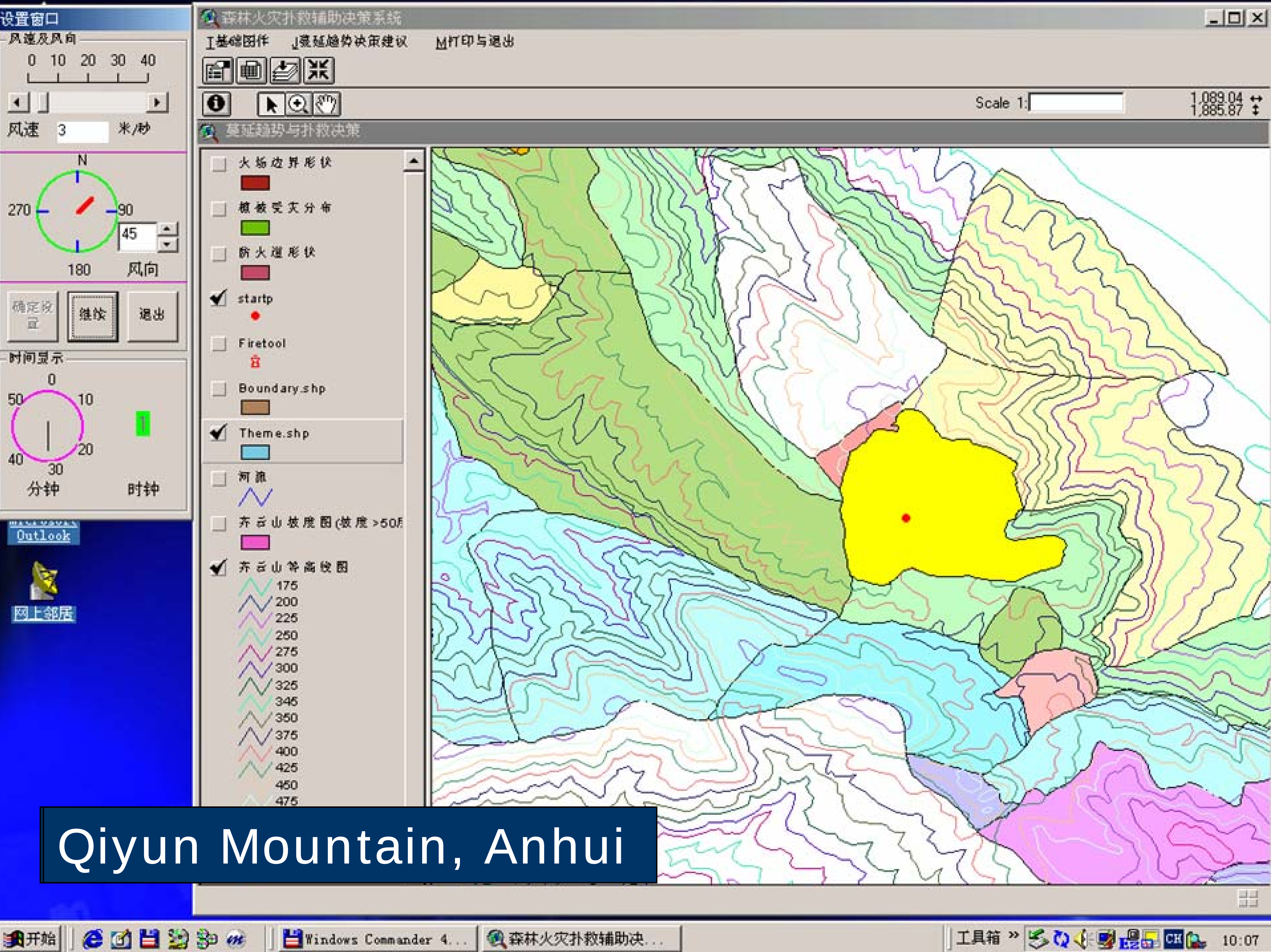
Suppression methods ← GIS



Qiyun Mountain, Anhui



Qiyun Mountain, Anhui



Qiyun Mountain, Anhui

②Fire Growth

- Interaction of Pyrolysis, Phase Change, Fluid Flow, Heat Transfer and Chemical Reactions
- Nonlinear Dynamical Models of Fire and Relevant Nonlinear Numerical Methods

Fire whirl

Flashover

Backdraft

Fire Growth---- Backdraft

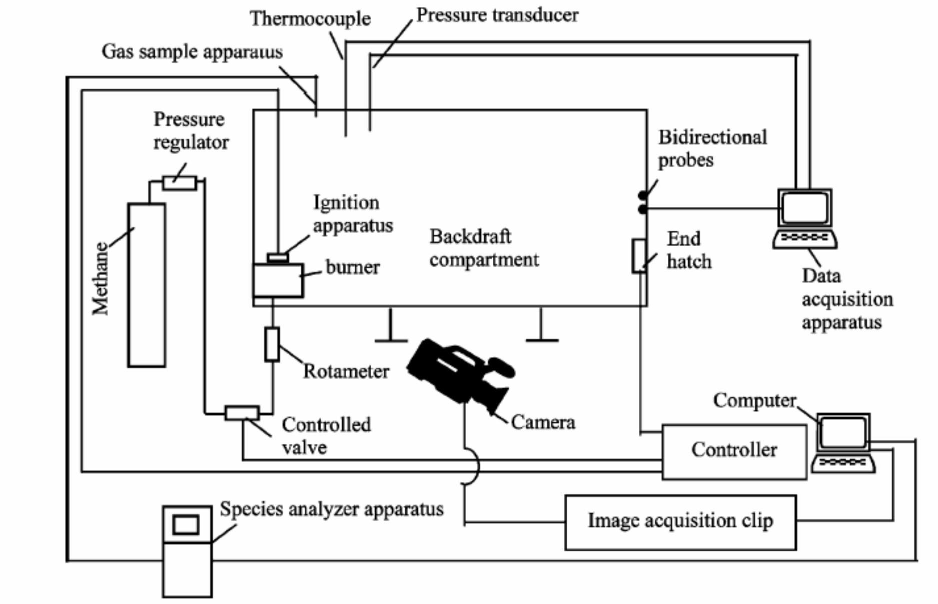


Fig. Schematic of the backdraft experimental apparatus at SKLFS

- Developed an experimental apparatus for backdraft experiments.
- Revealed that the key parameter determining the backdraft occurrence is the mass fraction of unburned fuel when subject to fire source.
- Established a simplified mathematical model based on energy balance, whereby it is demonstrated that backdraft phenomenon is one kind of typical catastrophe behavior.

Fire Growth----Backdraft






Experiment of backdraft for liquid and solid fuels

Backdraft Experiment of Liquid Fuels

Fuel：industrial alcohol

Fire Growth---- Flashover

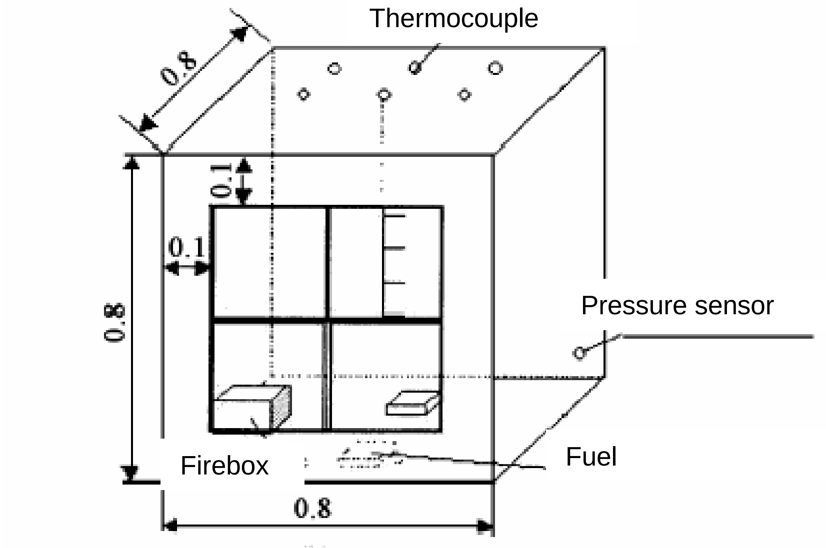


Fig. Schematic of the flashover experimental apparatus at SKLFS

- Developed an experimental apparatus for flashover experiments.
- Revealed that flashover is in essence a phenomenon of swallowtail catastrophe
- Revealed that different fuel species generally be not involved into the flashover simultaneously.

Fire Growth---- Fire Whirl

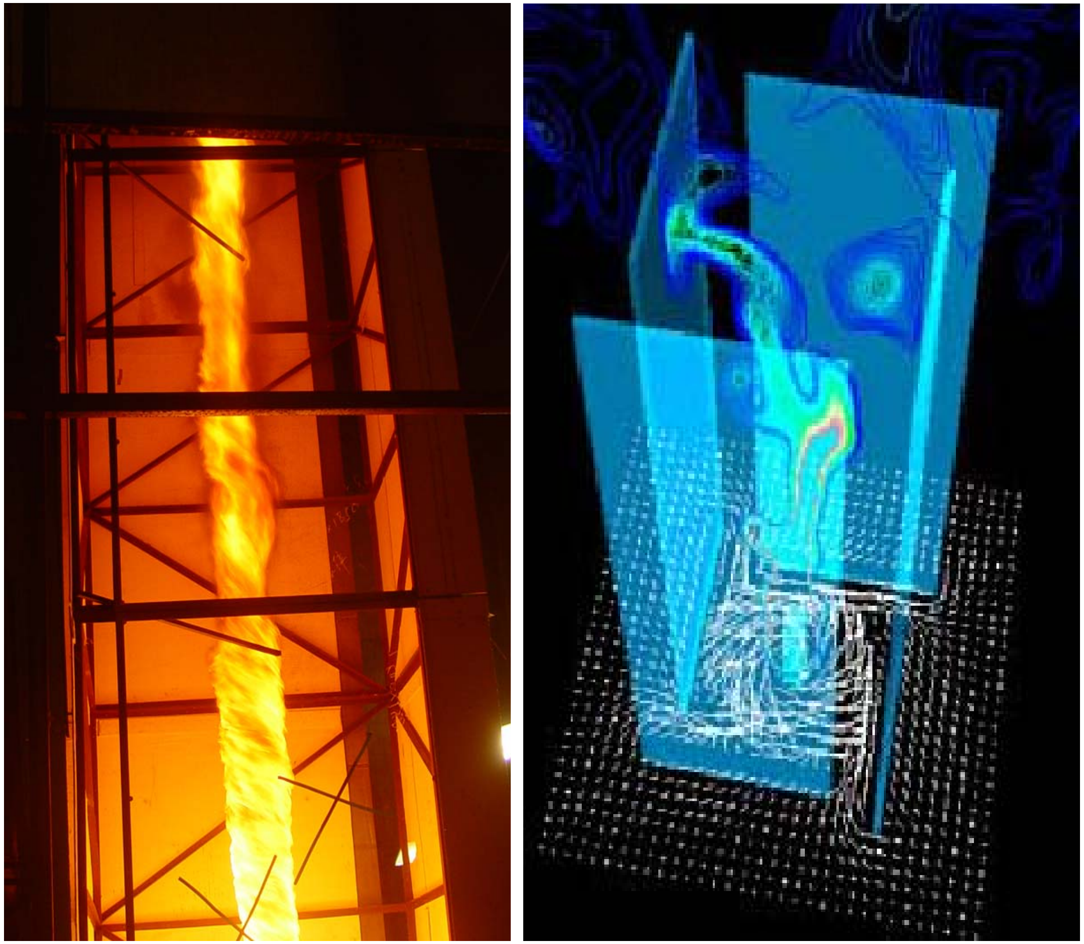
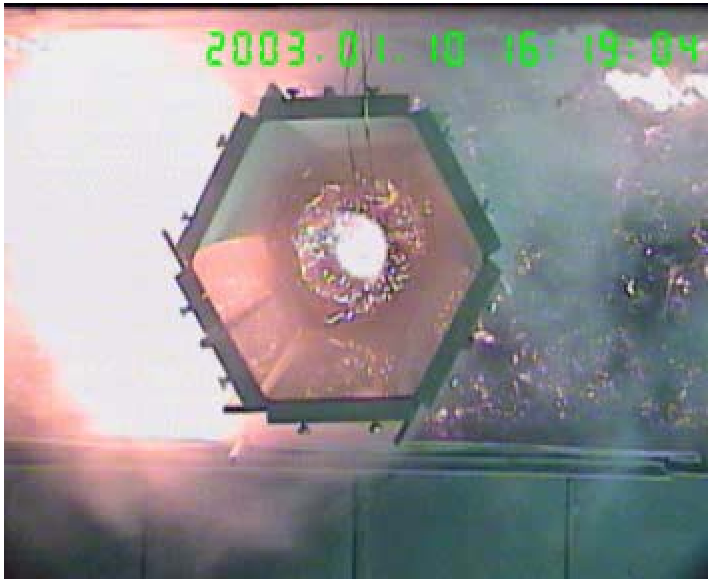


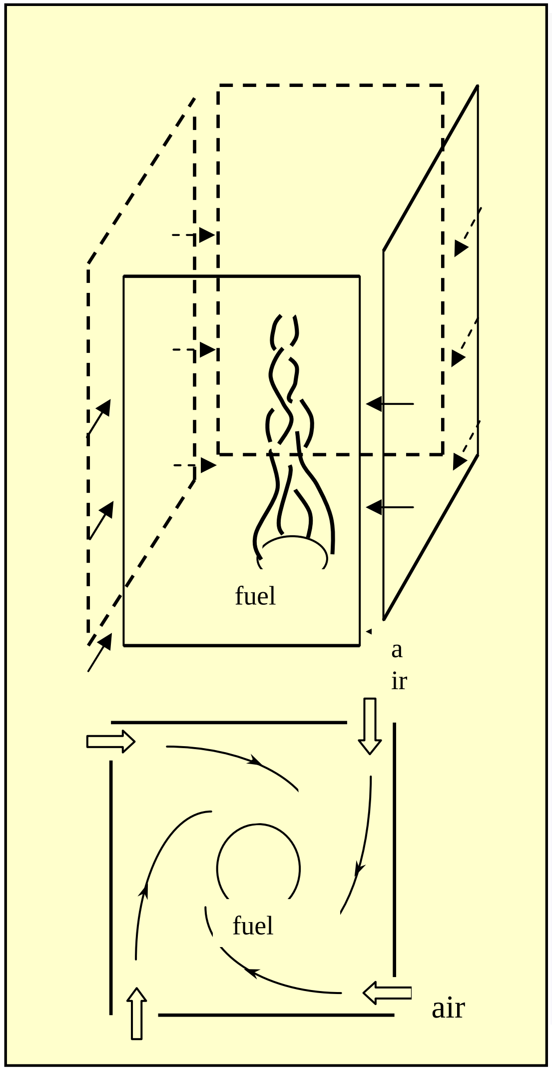
Fig. Firewhirl experiment and simulation at SKLFS. The enclosure: 15m high
(Cooperated with Satoh)

- Developed a large scale firewhirl apparatus (15m high) at SKLFS.
  - Based on the physical model of Satoh and Yang
  - Used four fireproof channel walls to form the enclosure.
- The initial experiments realized a 9m high firewhirl.

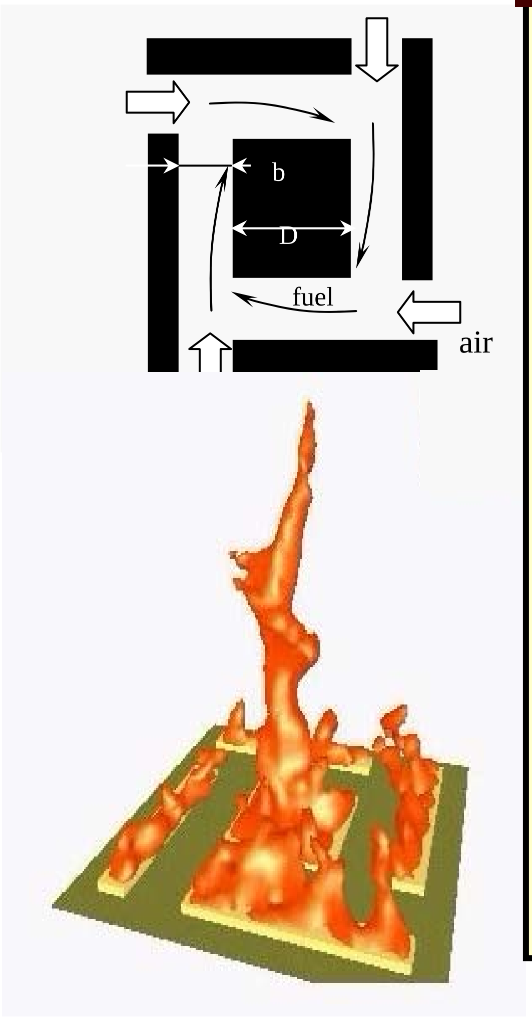
Fire Growth---- Fire Whirl Experiments



Fire Growth---- Fire Whirl



Model of Satoh & Yang



Fire-wall firewhirl model

■Fire-wall firewhirl model

➢**Four bars of liquid fuels** are used to produce the enclosure where firewhirl may be induced.

➢Numerical results show that under certain conditions firewhirl can **be induced.**

➢The new model scheme has **higher similarity** with some practical situations especially in wildland fires.

③Fire Modeling

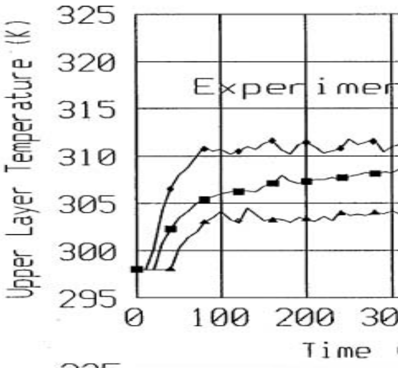
- Fire Behavior Simulation
- Movement of Fire Smoke in Different Kinds of Spaces
- Engineering fire modelling methods

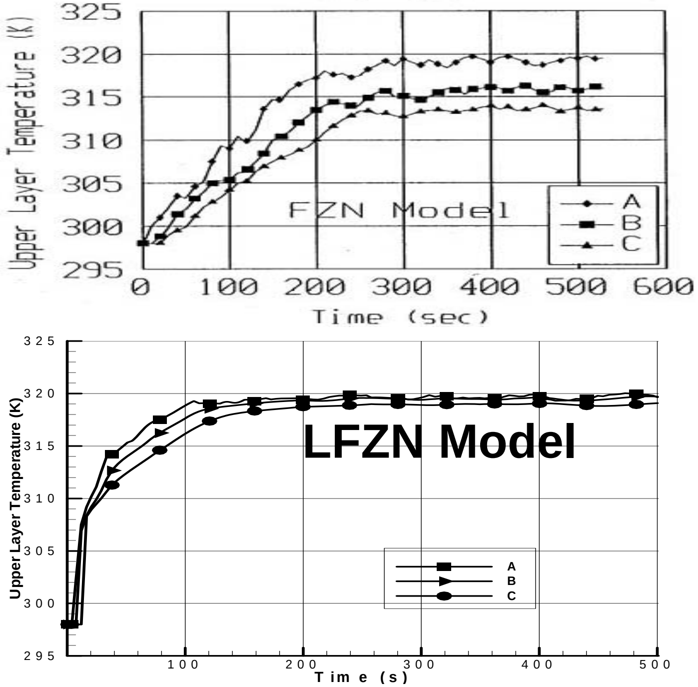
Fire Smoke

Fire Modelling---- LES-Field-Zone-Network model

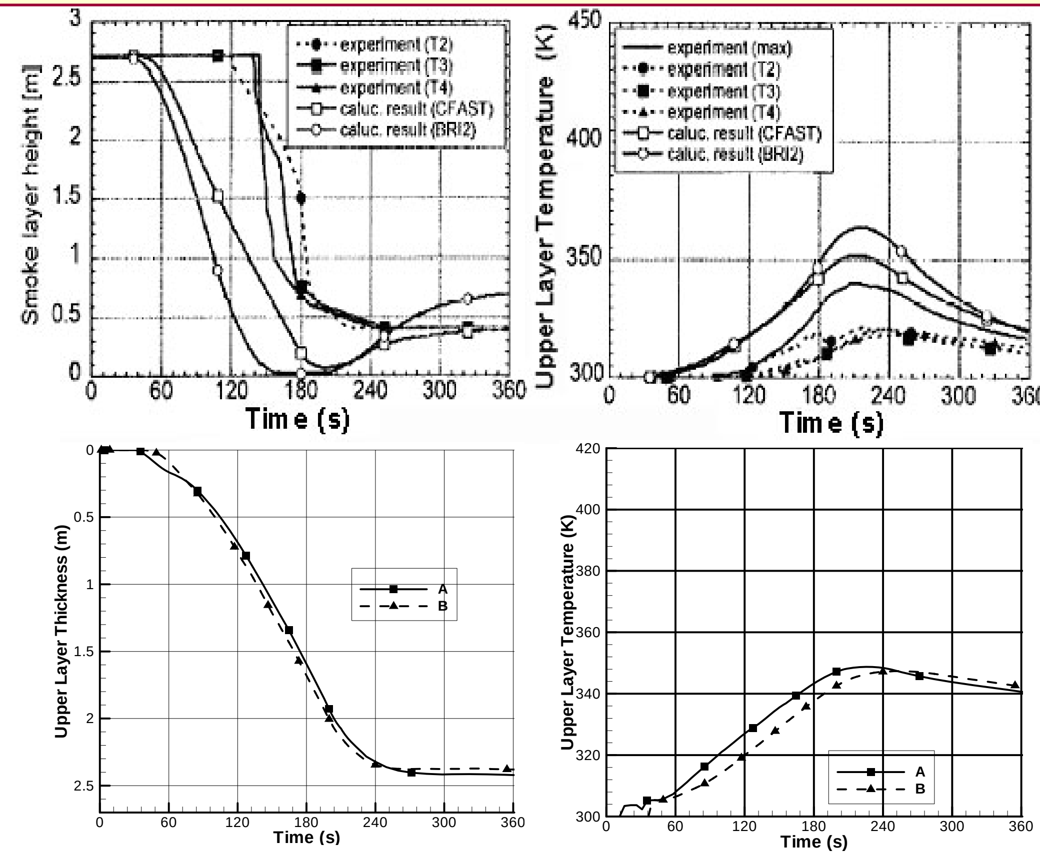
To simulate the fire smoke movement in a single fire room

- Use the Large Eddy Simulation (LES) technique to filter three-dimensional compressible Navier-Stokes equations at low Mach number
- Show better performance than ordinary FZN model and CFAST.





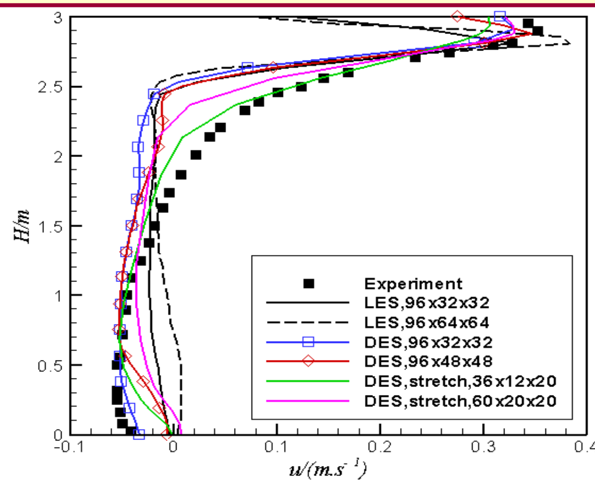
Comparison of experiments *v.s.* ordinary FZN & LFZN's simulation

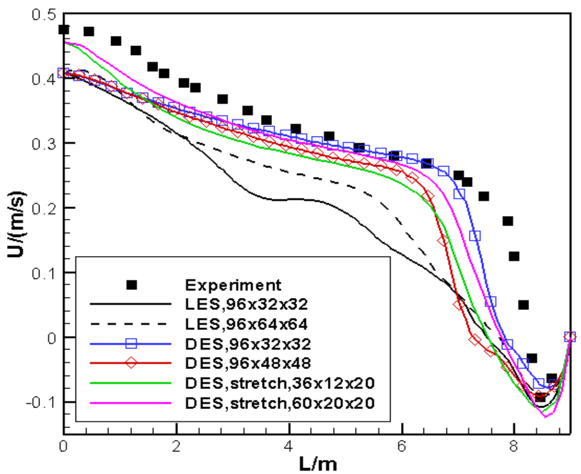


Comparison of CFAST & LFZN's simulation

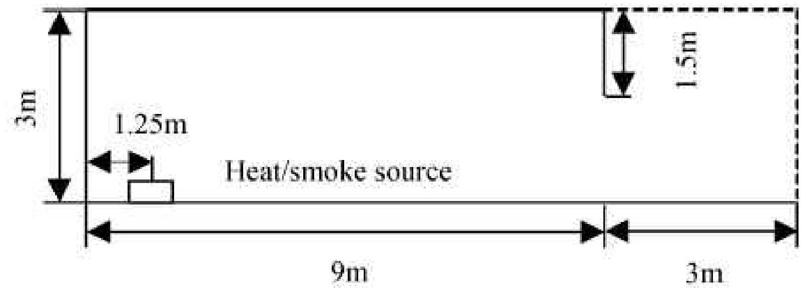
Fire Modelling---- Two combined schemes (RANS/LES, RANS/DES)

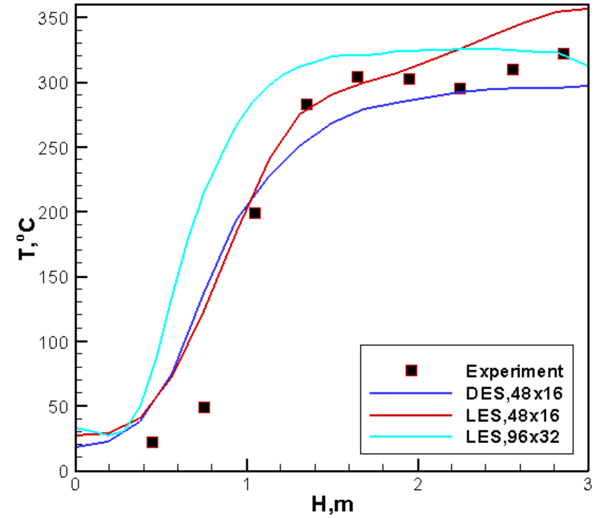
- **New numerical methods of turbulence in fire simulation**
- **Hold the accuracy of LES/DES and the high computing efficiency of RANS.**





Verification：forced convection

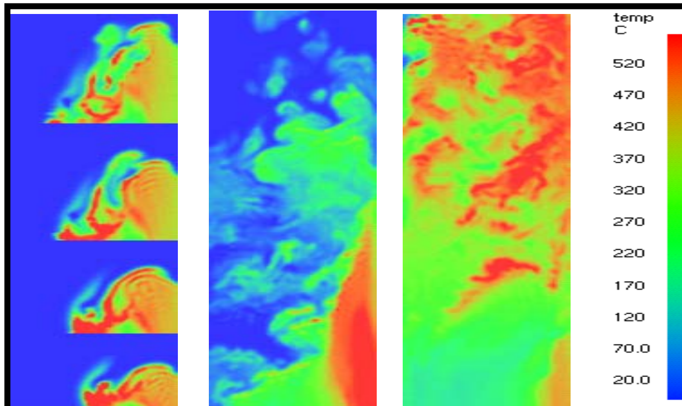




Application: fire simulation of shopping mall

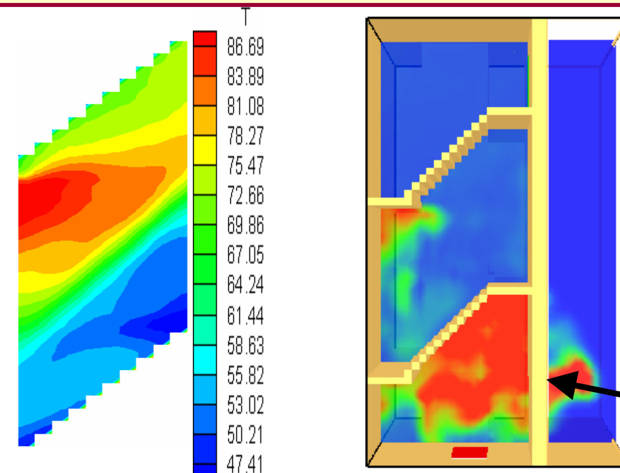
Fire Modelling---- Simulation of smoke movement

Simulation of fire and smoke by LES in silo, storeys and stairwell (the backdraft phenomenon was predicted)



(a) (b) (c)

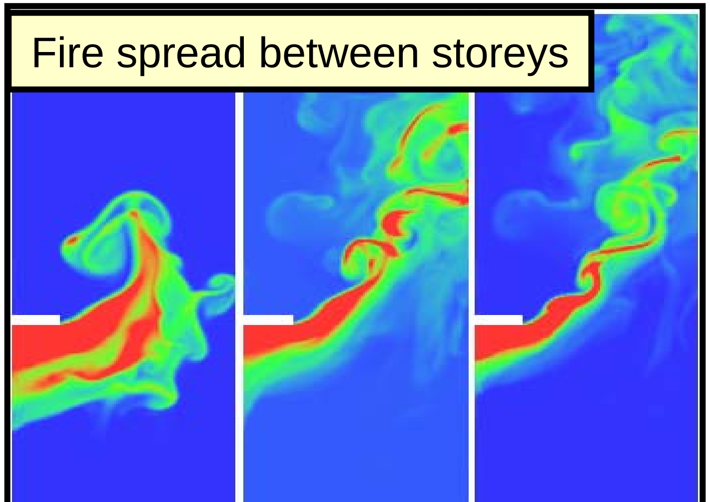
Smoke movement in silo



Fire spread and smoke movement in a typical stairwell

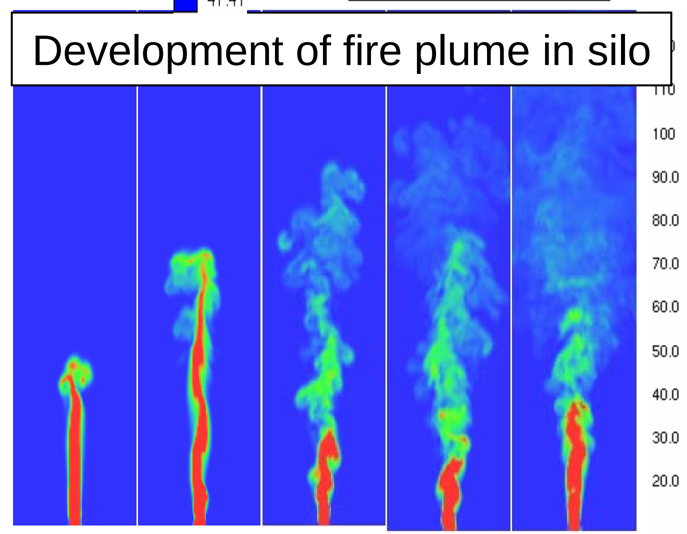
backdraft

Fire spread between storeys



(a)t=2.34s (b)t=2.81s (c)t=3.00s

Development of fire plume in silo



t=1.4s t=2.1s t=2.8s t=4.2s t=6.4s

Fire Modelling---- Fire and Smoke Experiments in USTC/PolyU full-scale experiment atrium

- **Inner:22.4m(long)×12m(wide)×27m(high)**
- **Study of fire plume, smoke movement and ventilation**

④ Fire Statistics

- Carbon Emission of Forest Fire
- Self-organized Criticality Behavior

Fire statistics---- Direct Carbon Emissions from Chinese Forest Fires

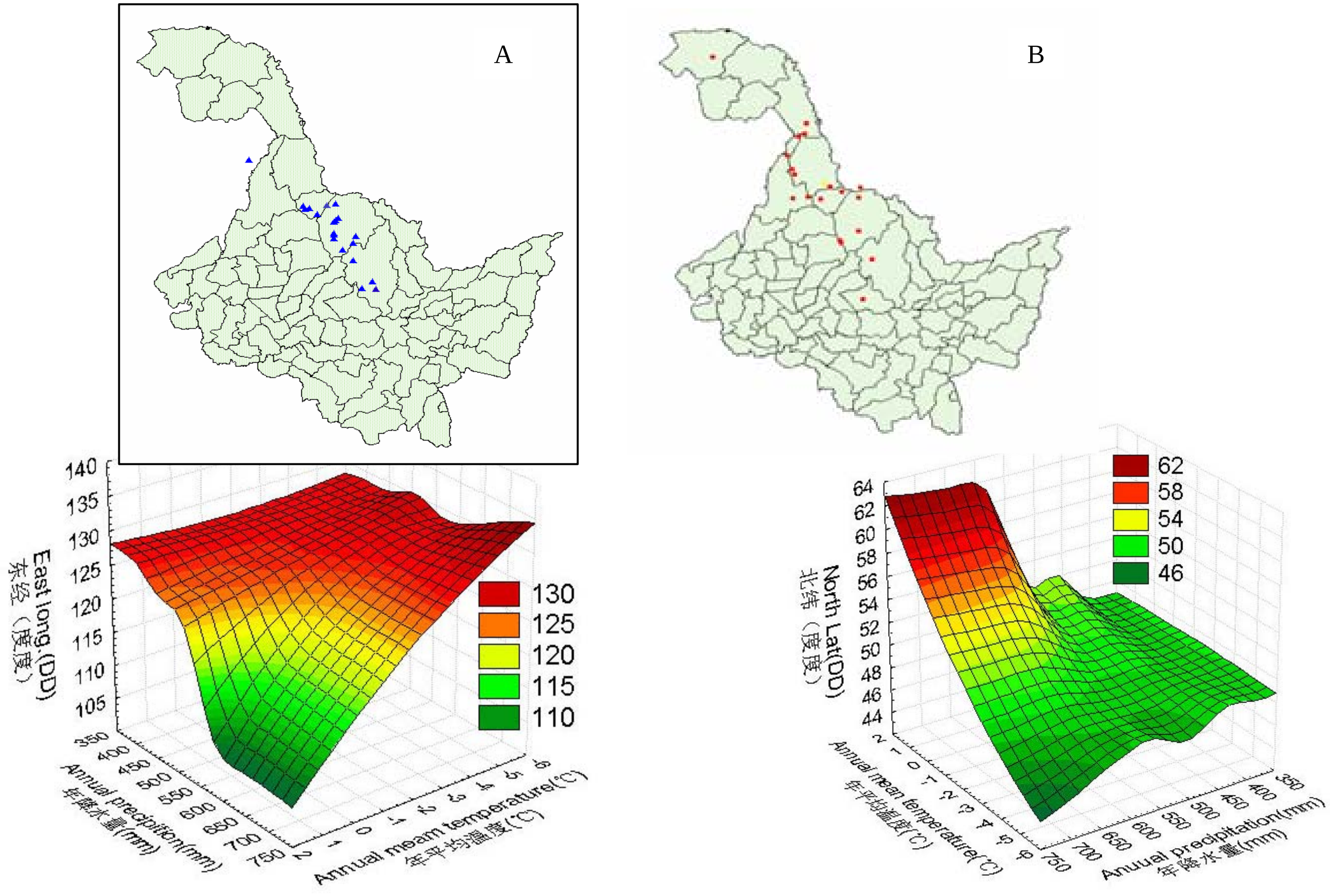
Calculated the consumed biomass due to forest fires according to the statistics of forest fires in China from 1991 to 2000

- Forest fires burned average 5-7Tg biomass each year and directly emitted carbon 20.24-28.56Tg, CO_2 74.2-104.7Tg, CH_4 1.797-2.536Tg, smoke aerosols 0.999-1.410Tg.

- The average emission of carbon dioxide accounts for 2.7-3.9% of the total emission of China (using the data of 2000), CH_4 3.3-4.7%.

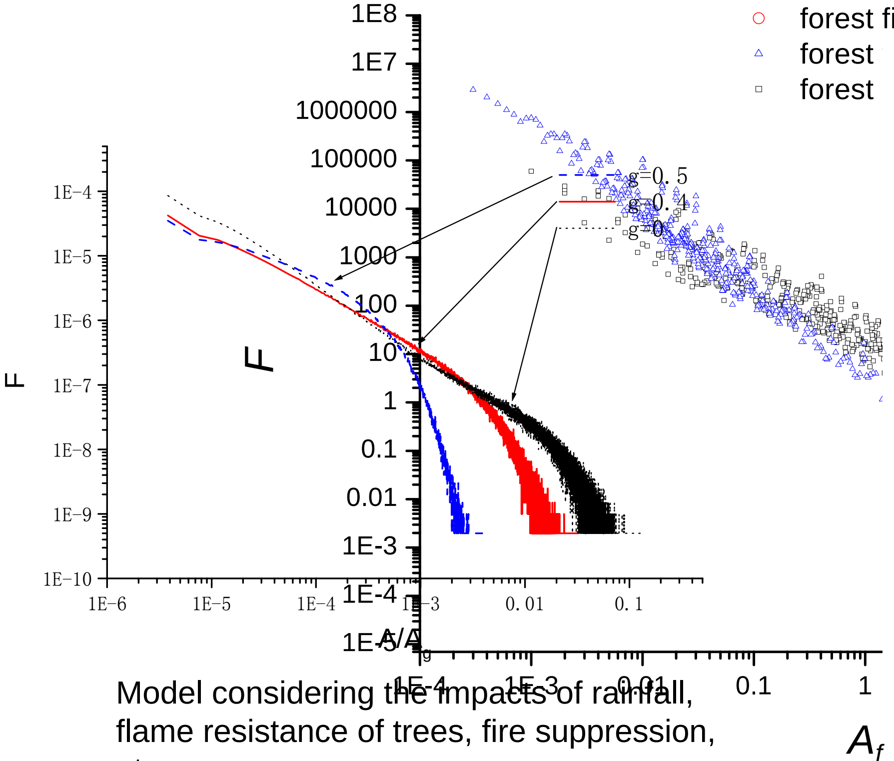
Fire statistics---- Spatial Fluctuation of Forest Fires and Their Response to Global Change

- Forest fires have circles and frequency in time.
- Annual precipitation and annual mean temperature have important impact on the fluctuation of centroids of annual fire scars and annual fire points.

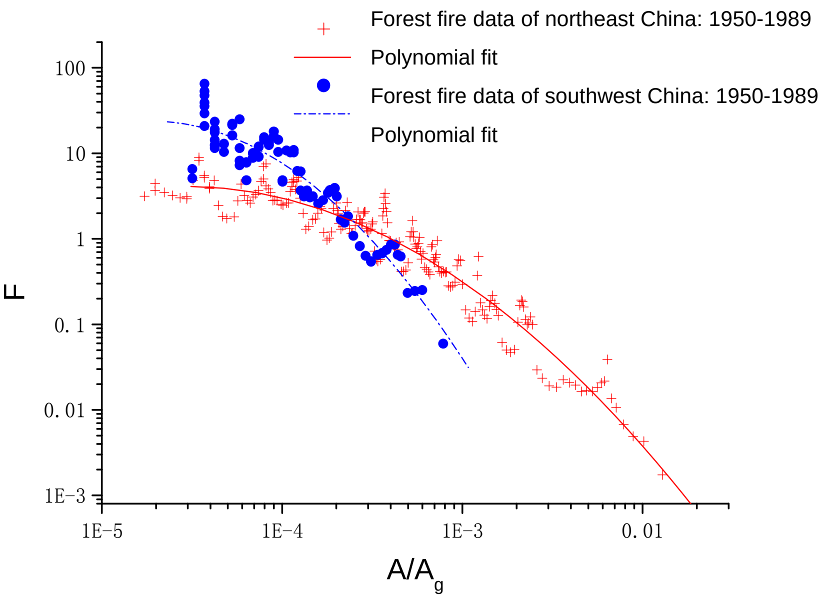


Fire statistics---- SOC properties of forest fires

- **Self-organized criticality (SOC) behavior characterized by the power-law relation of frequency-size distribution exists in the forest fires data in China and other countries.**
- **New forest fire model considering the impacts of rainfall *et.* can explain some features of the data, like heavy tail.**



Model considering the impacts of rainfall, flame resistance of trees, fire suppression, etc.



Comparison: forest fire data

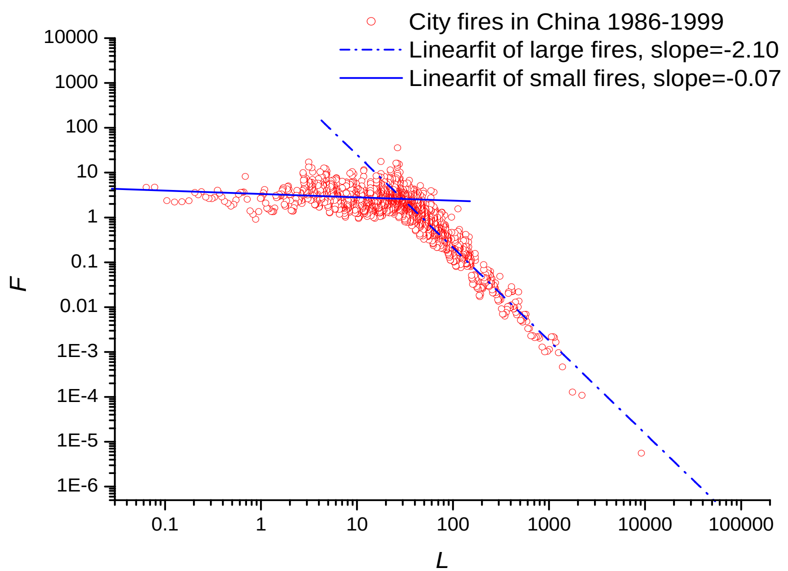
SOC behaviour of forest fire data

Fire statistics---- SOC properties of city fires

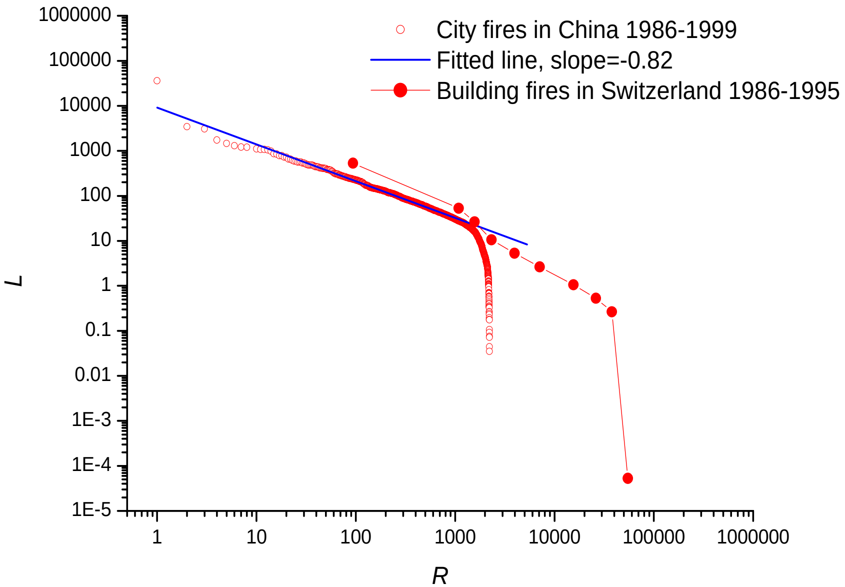
■The frequency-loss distribution of city-fire data in China satisfies a good two-segment power-law relationship.

■Large fires satisfies Zipf Law distribution.

The power-law relation is invariant with scale and time, i.e. fires in different places or in different periods will have the same distribution characteristics.



Frequency-loss distribution of city fires in China



Zipf plot of fires in China and Switzerland

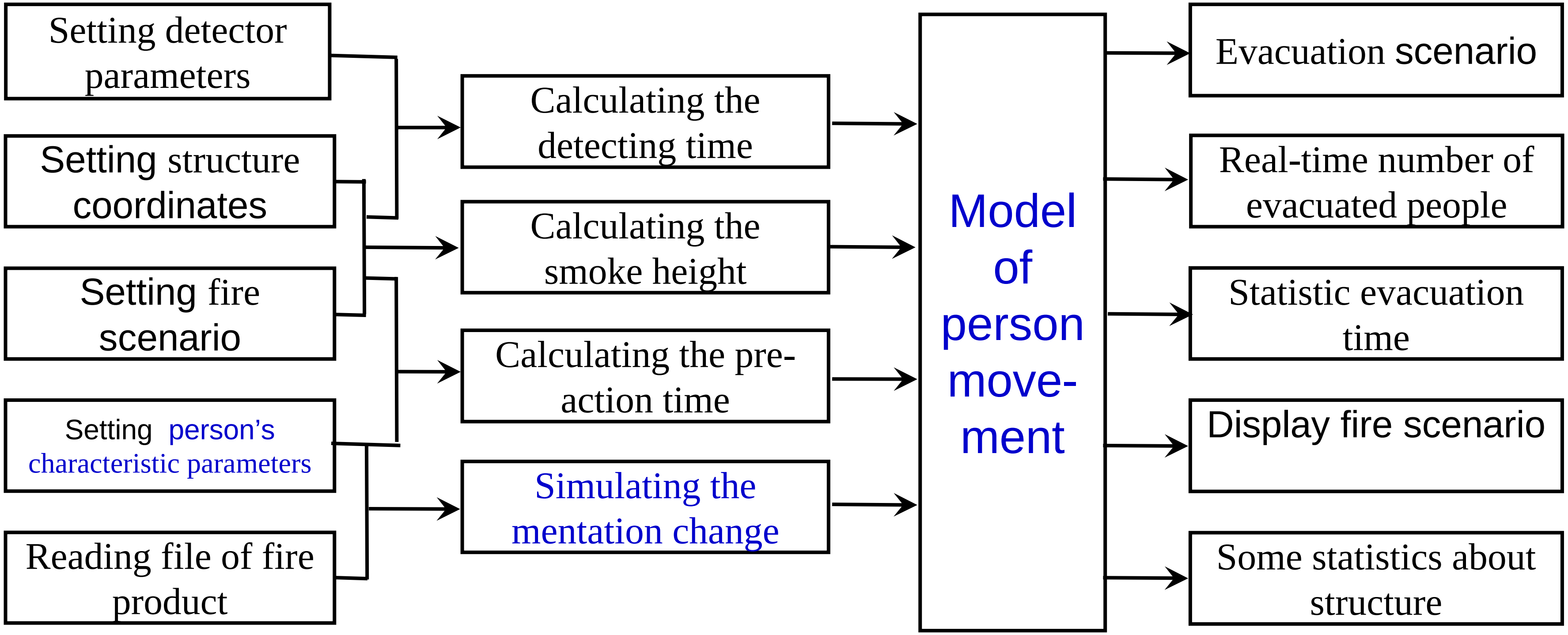
⑤ FIRE RISK ASSESSMENT METHOD

- Evacuation assessment
- Engineering application

Houses after fire

Fire risk assessment ---- Combined Fire Evacuation (CFE) model

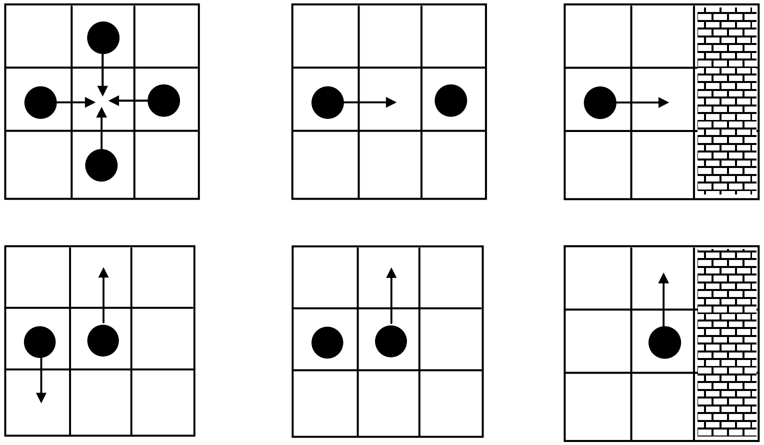
- **Considering the human behavior during evacuation.**
- **Integrating the effect of fire development and smoke.**

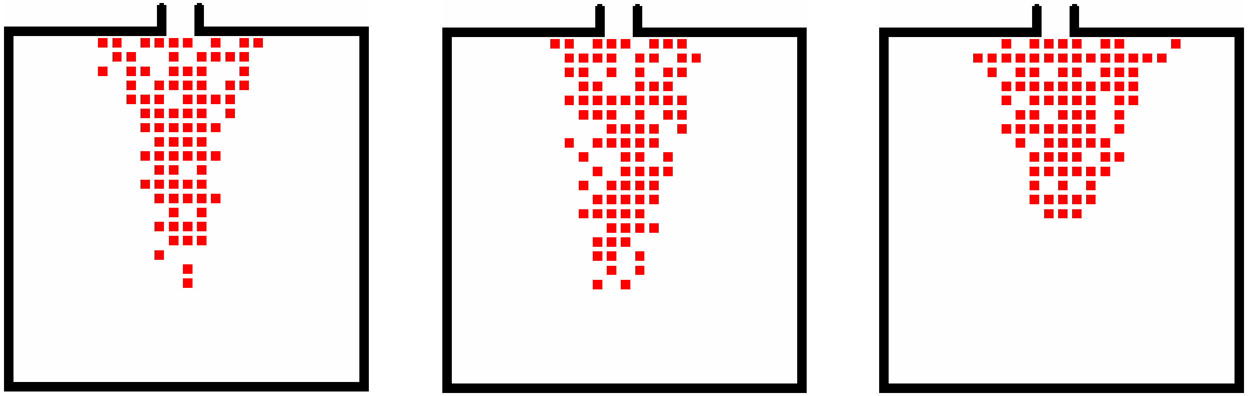


Organization of the CFE model

Fire risk assessment ---- CAFE model (Cellular Automata with Force Essential)

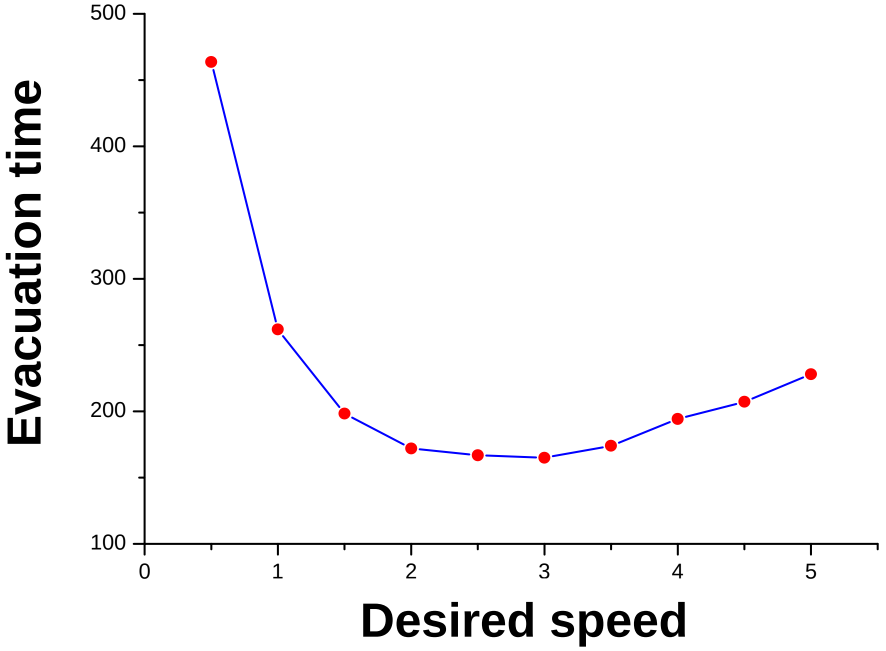
- Attraction: Exits etc.
- Repulsion:
- Friction:

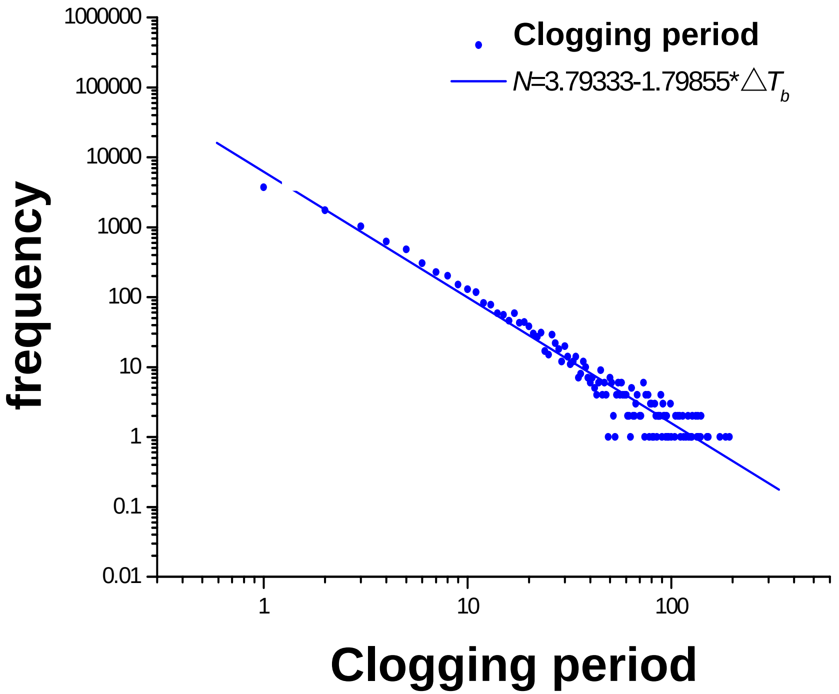




Desired speed: 1m/s 3m/s 5m/s

Fire risk assessment ---- CAFE model (Cellular Automata with Force Essential)





Faster-is-slower phenonemon

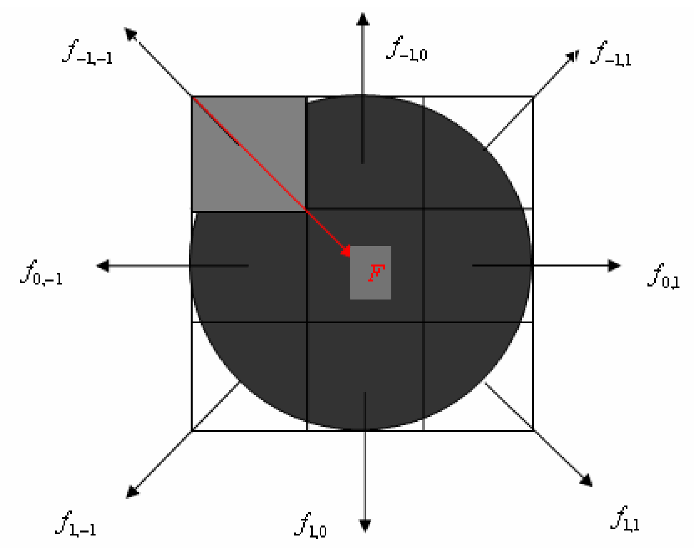
Power-law distribution of clogging period

Fire risk assessment ---- Multi-grid model

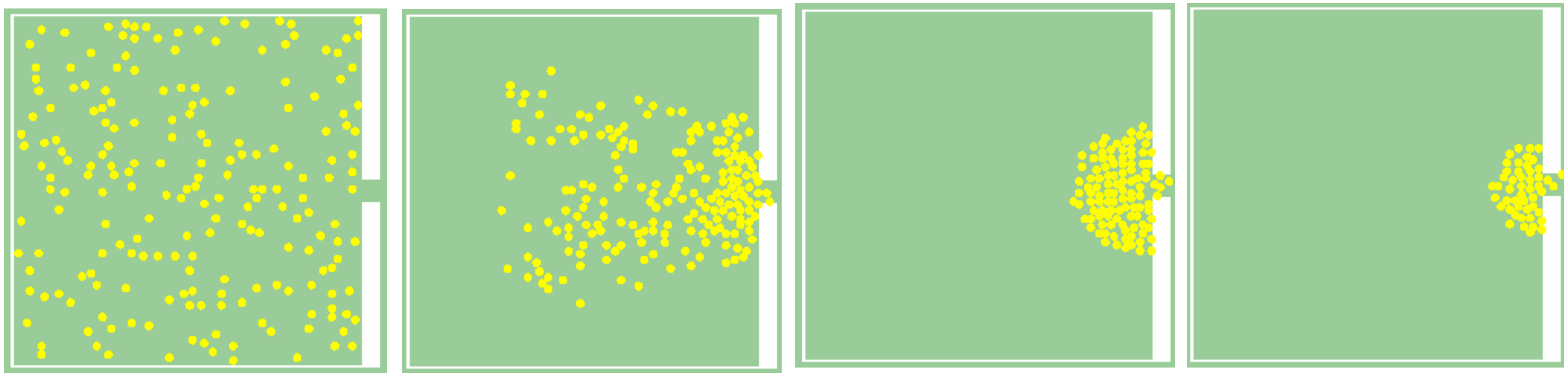
- Continuous model
  - originate from fluid dynamics
  - solving differential equations
  - slow calculation speed

- CA or LG model
  - simple rules
  - difficult to calculate forces
  - fast calculation speed

- Multi-grid model
  - Fast calculation speed
  - Considering forces



Fire risk assessment ---- Multi-grid model

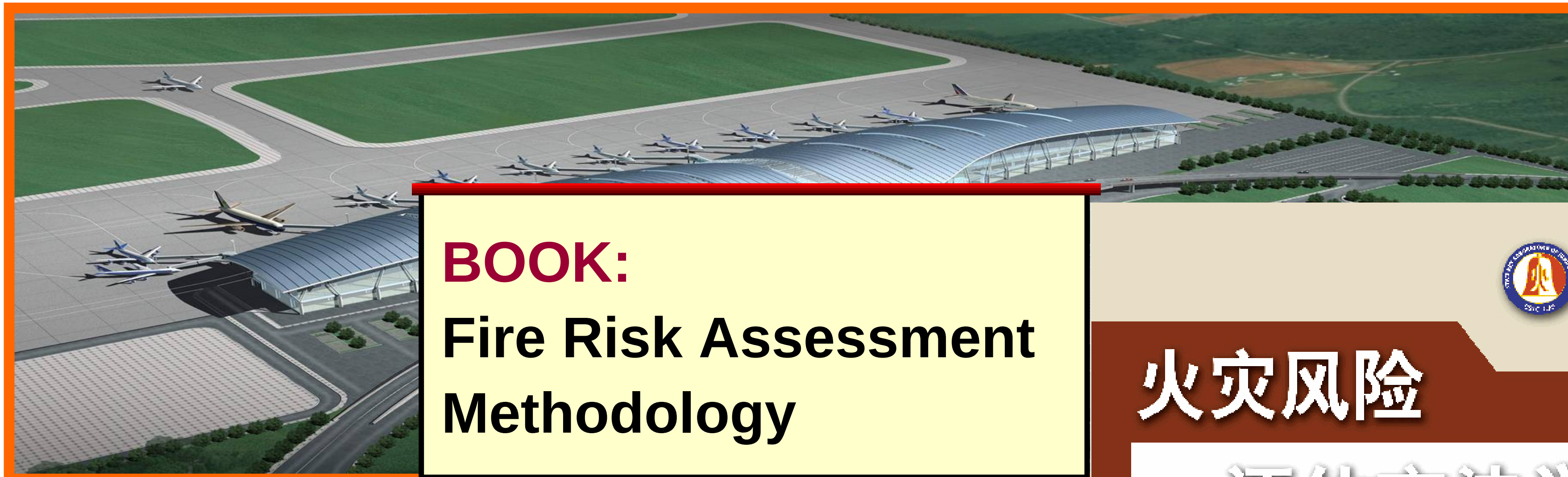


SONG WG et al. Simulation of evacuation processes using a multi-grid model for pedestrian dynamics. Physica A (in press)

Reviewers' comments

The introduction of finer grids makes it easy to incorporate social forces and quantify pedestrian interactions. It is an excellent model for studying pedestrian dynamics.

Fire risk assessment ---- *Application*

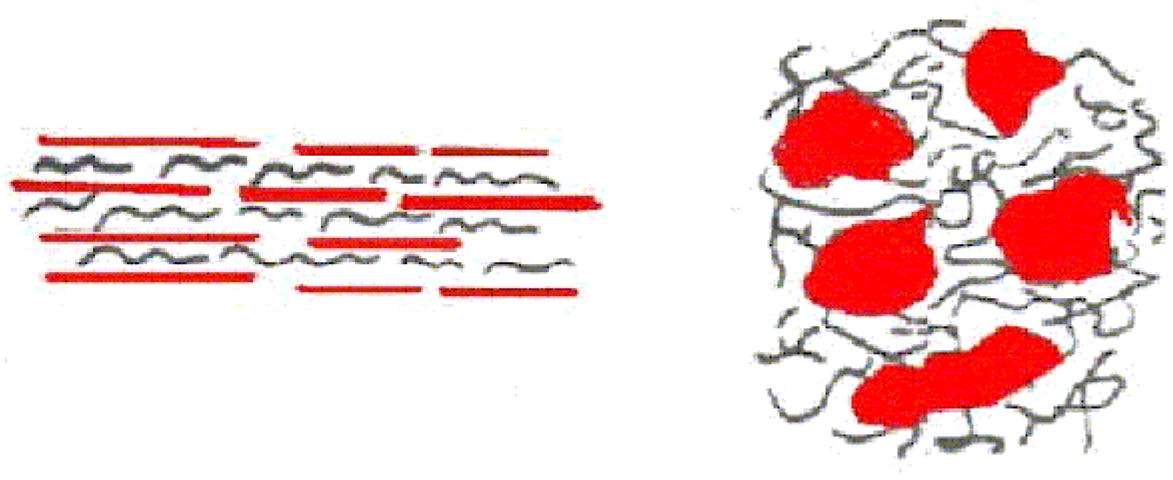


BOOK:

Fire Risk Assessment Methodology

⑥ (a) High Quality Fire Retardant Materials

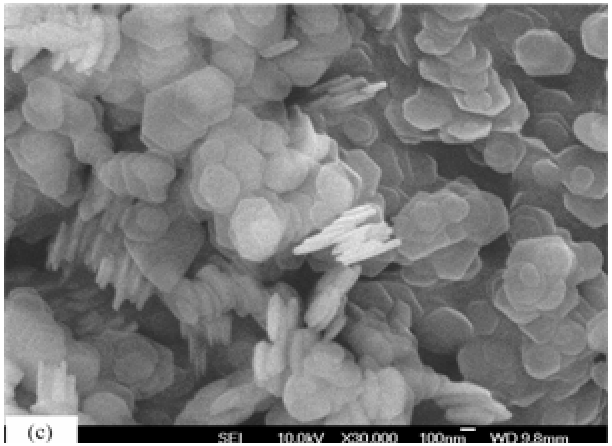
- Nanometre Fire Retardant Materials
- Fire Retardancy Mechanism of Halogen Free Materials

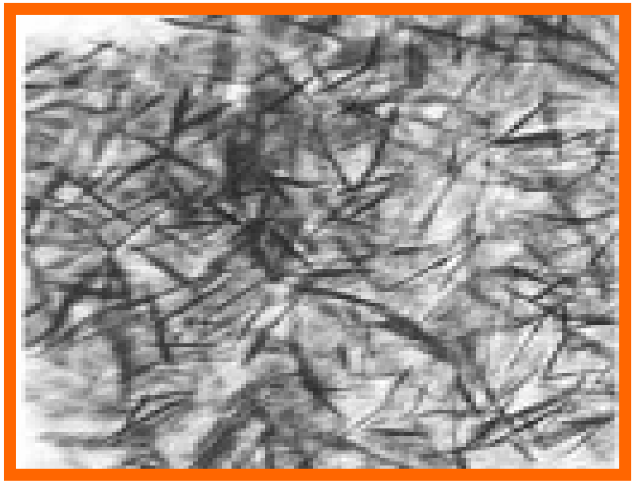


(a)Nanometer Materials (b) Ordinary Material

Fire Retardancy----Mg(OH)2 nanocomposites

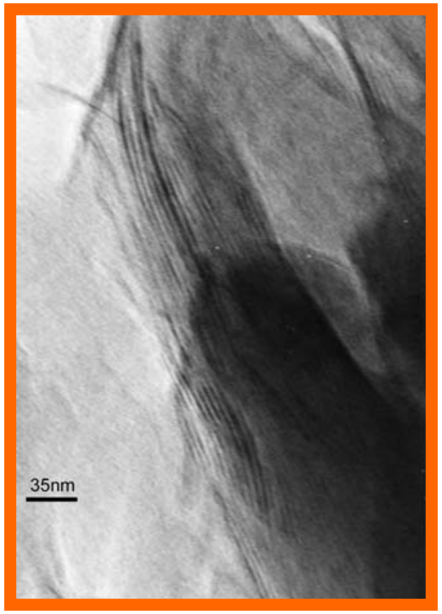
■**Successfully synthesized acicular, sheet, and rod-like Mg(OH)2 nanocomposites,**





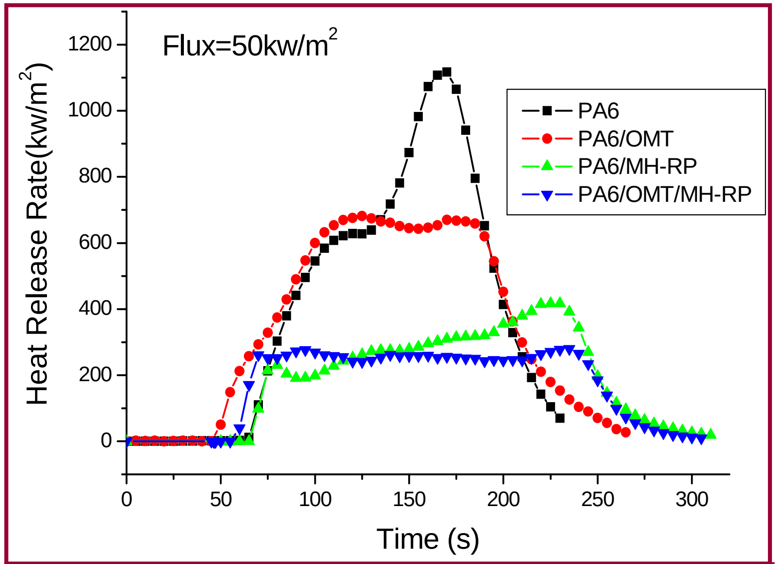
Fire Retardancy---- Multiplex nanocomposites

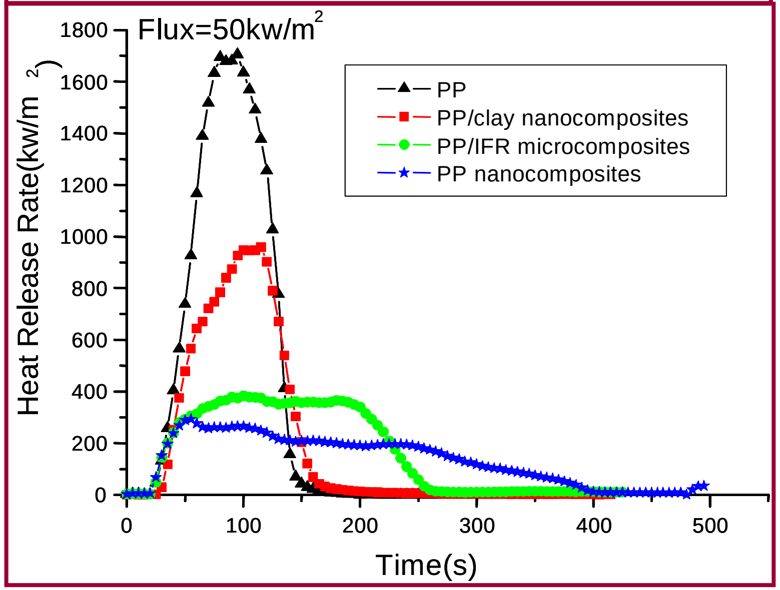
■**Multiplex nanocomposites, synthesized by a chromatographer and intercalation method, with high efficiency of fire retardancy**



PU/OMT **nanocomposites**

ABS/ OMT **nanocomposites**



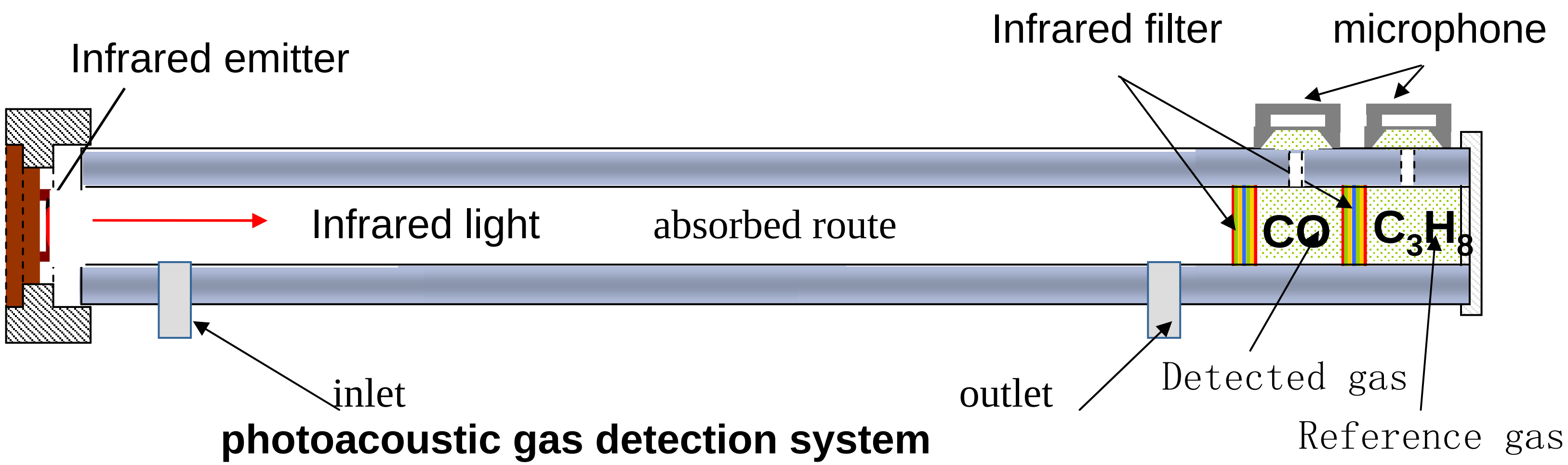


⑥ (b) Intelligent Recognition of Fire Signals

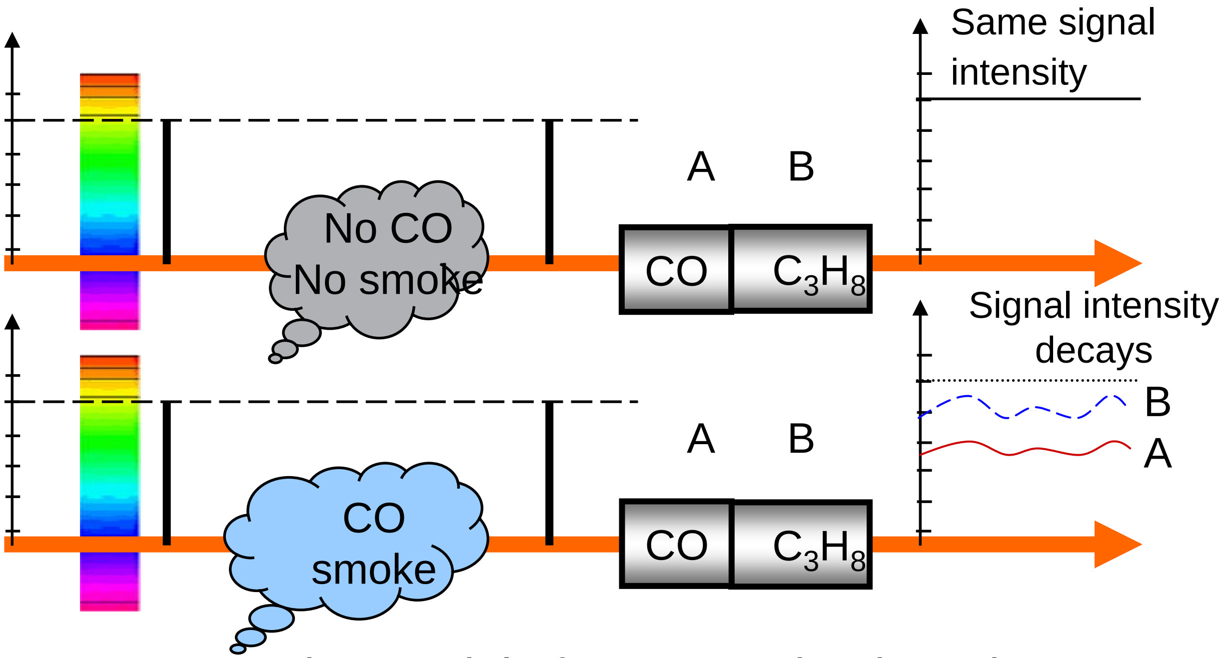
- Characteristics of Light, Smoke (heat, gas and solid particles) and Sound in Fire
- Multi-parametric and Multi-criteria Fire Signal Recognition Models

Features in the Early Period of Fire

Fire Detection----Photoacoustic gas detection



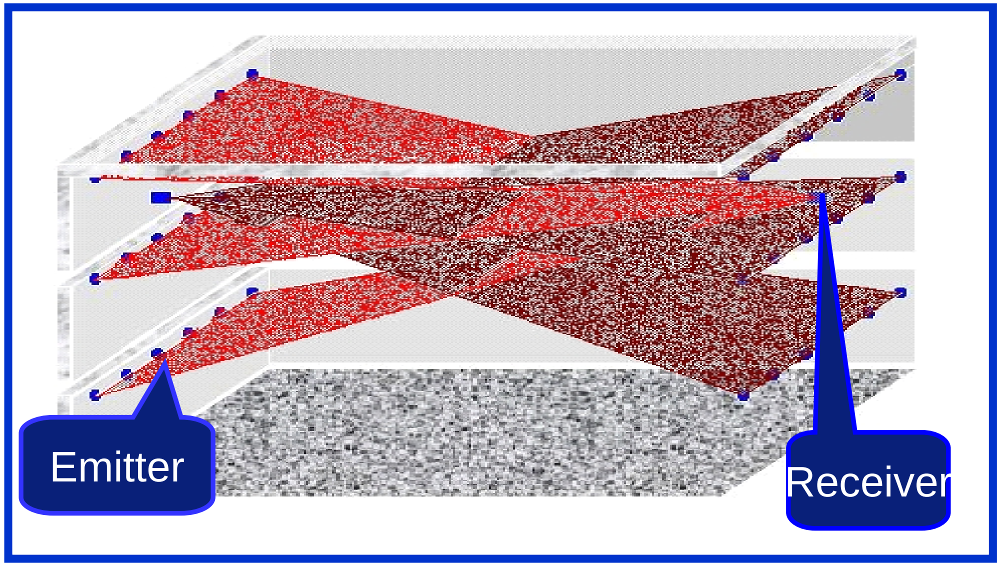
photoacoustic gas detection system



Processing model of gas—smoke detection

- developed the photoacoustic gas detection technique
- designed an unusual photoacoustic gas detection system

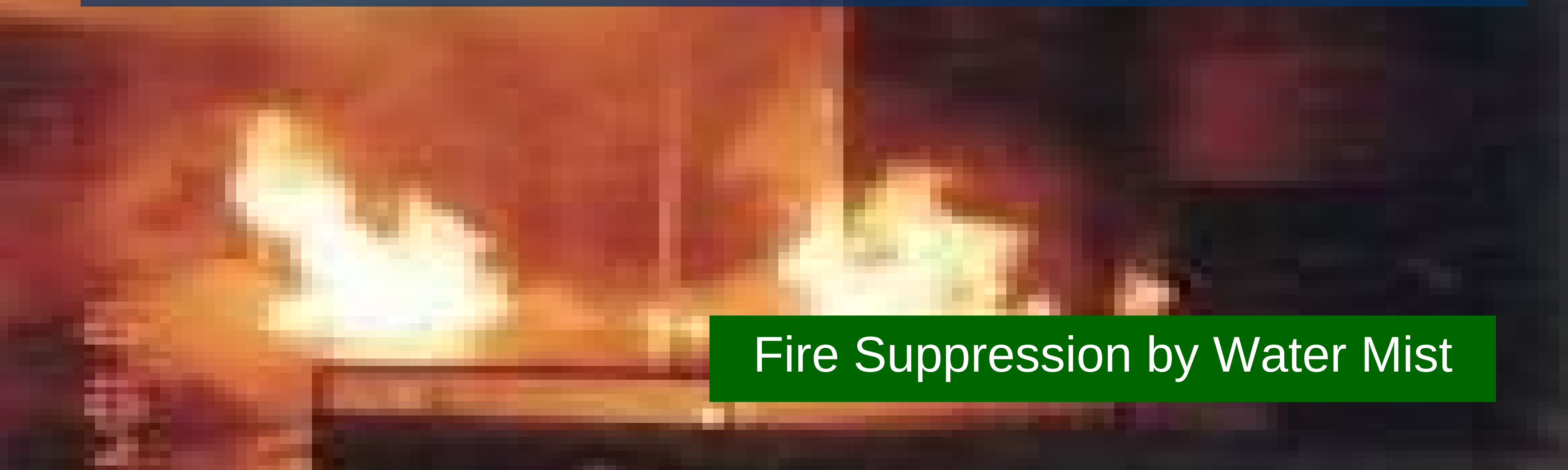
New Technology: Large space fire recognition, positioning and suppression system by multi-mode images



- **Fire detection by double waveband images→ Flame Detection**
- **Smoke detection by infrared video→ Smoke Detection**
- **Smoke recognition by laser images→ Smoke Recognition**
- **Photoacoustic gas detection → Gas Species Detection**

⑥ (C) Method of Fire Suppression with High Efficiency

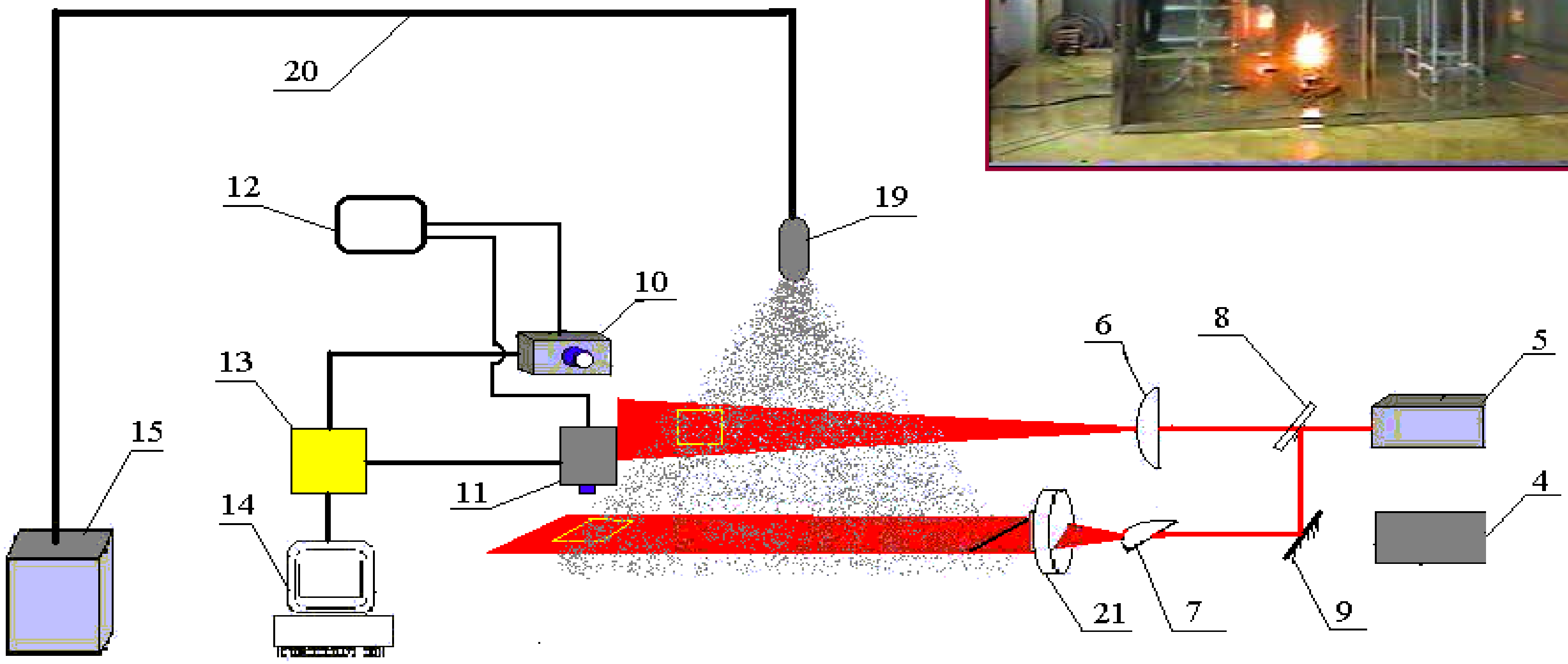
- Method to Generate Water Mist and its Characterization
- Effect of Water Mist to Fire and Smoke
- Mechanism of Gaseous Fire Suppression



Fire Suppression by Water Mist

Fire suppression---- Water mist characterization

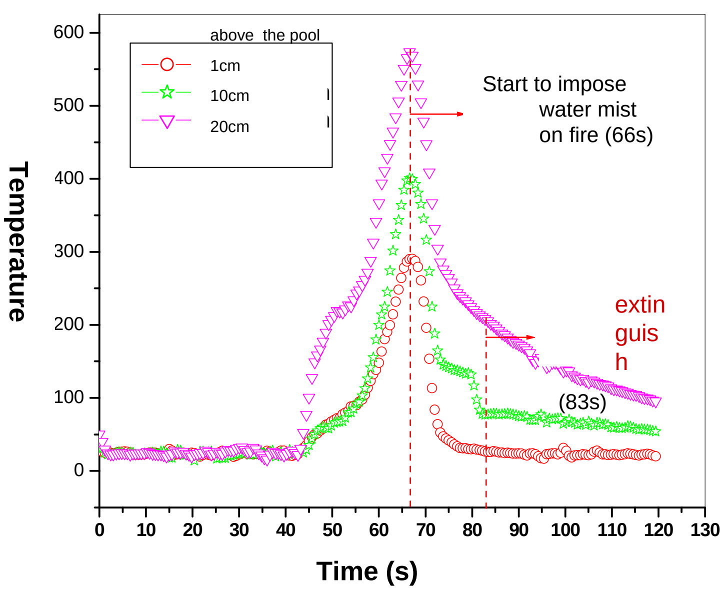
- Establish one system for characterization of water mist
- Non-intrusive method to characterize water mist by droplet size and velocity distribution, the water mist atomization angle and the breakup length



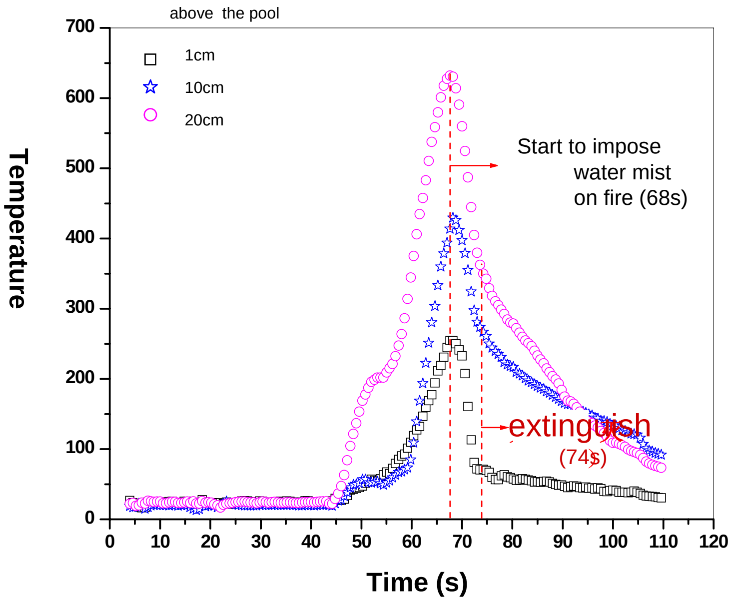
Schematic apparatus of measurement

Fire suppression---- Water Mist with Additives

- Add some additives into water mist to enhance fire suppression effectiveness
- Find optimal mass concentration for the fire suppression effectiveness.



Kerosene fire （no additive）

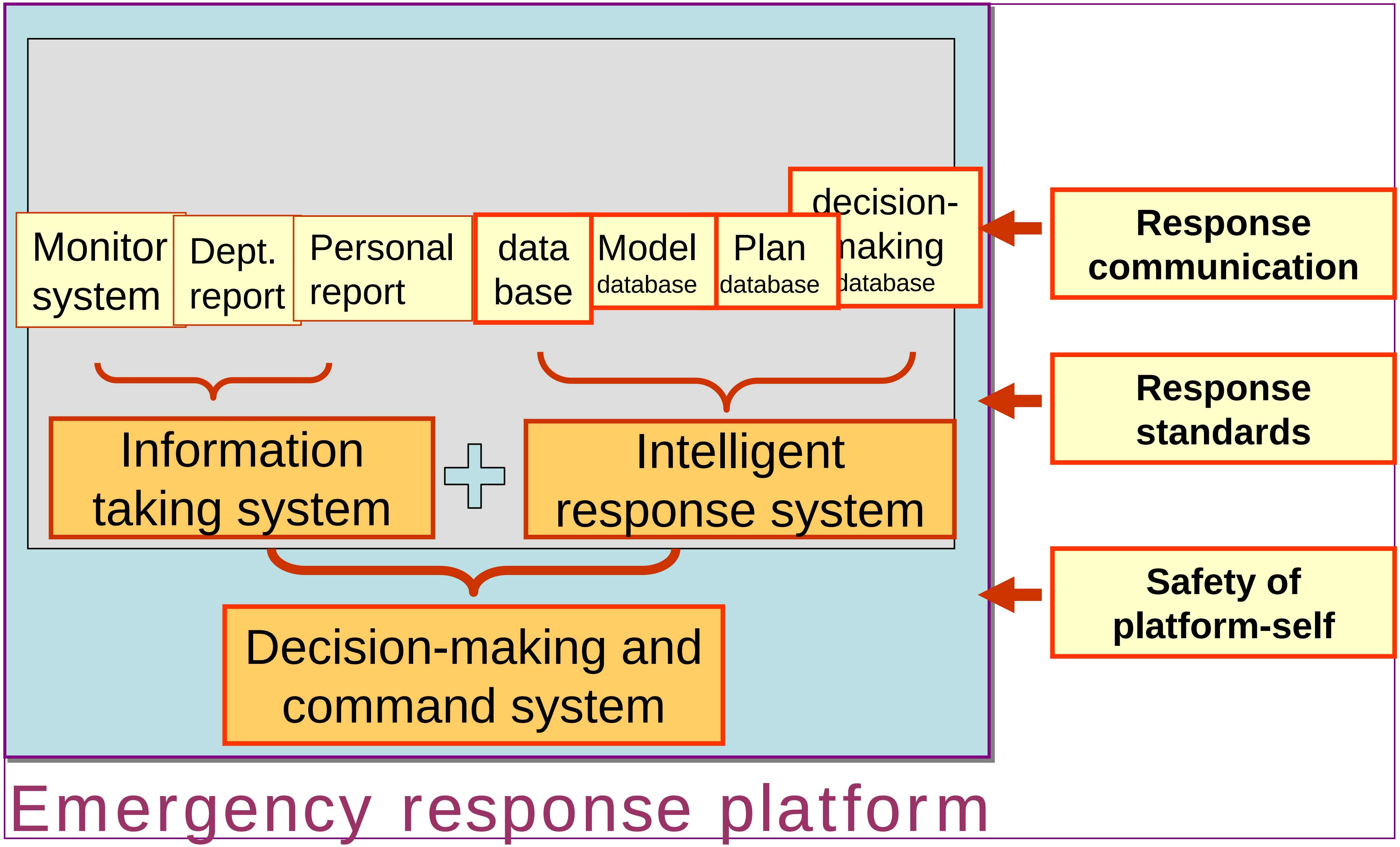


Kerosene fire（0.15% additive）

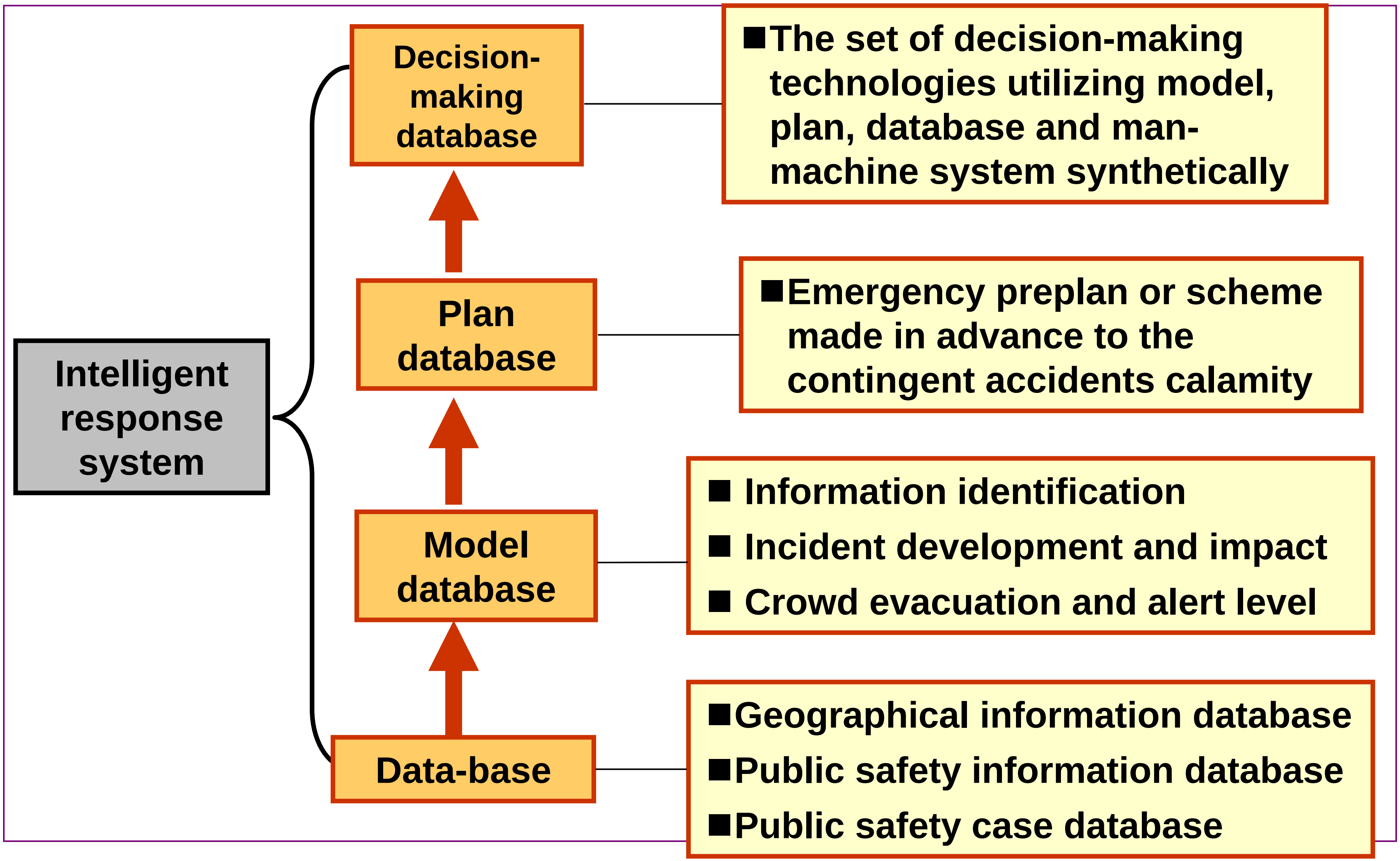
Emergency response platform-Function

- Information-sharing including basic geographical information and public safety information.
- Quantify the risk and make alert.
- Analysis and optimization of available options for rescue operation.
- Assisting users to create graphic presentations for visualizing and understanding the risks and solutions.
- Optimize the decision-making process, give commander the tools to make better decisions for rescue operation.

Components of response platform

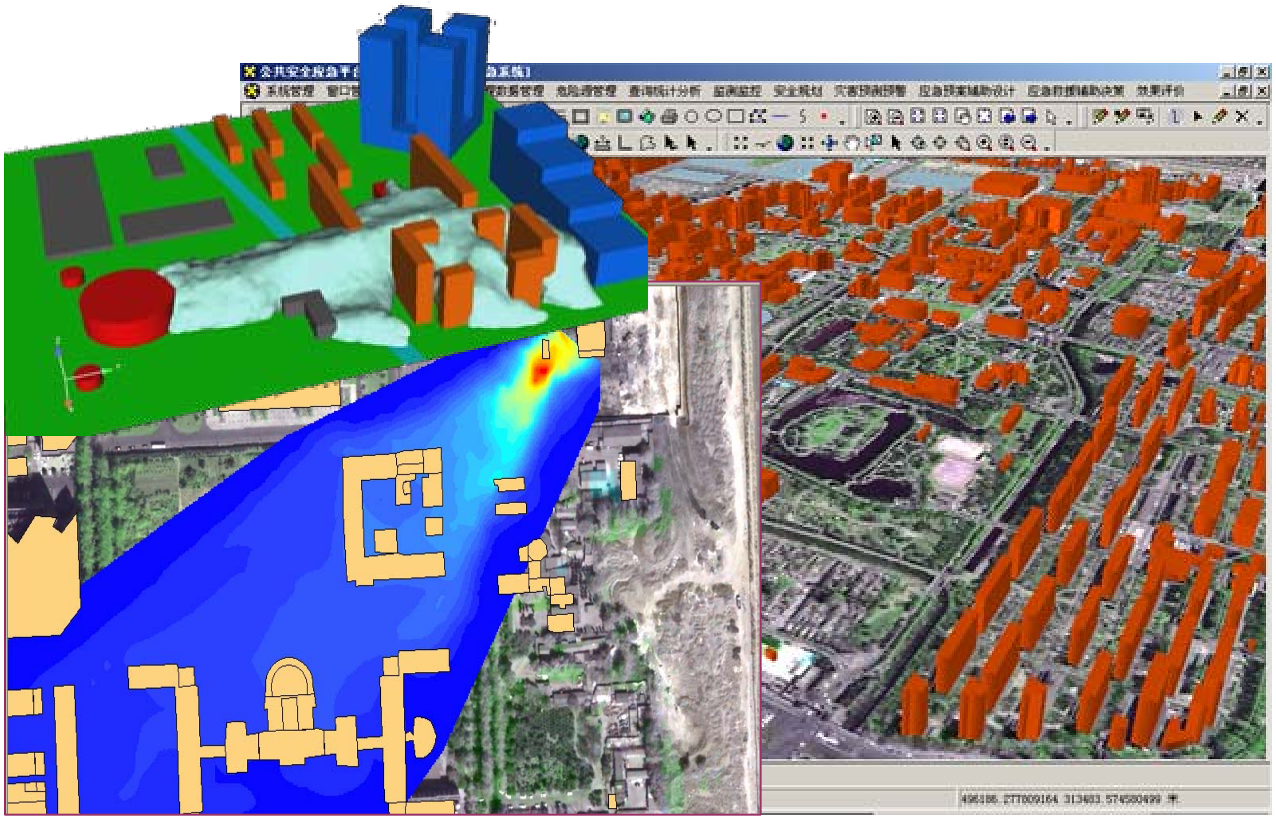


Intellectual response system

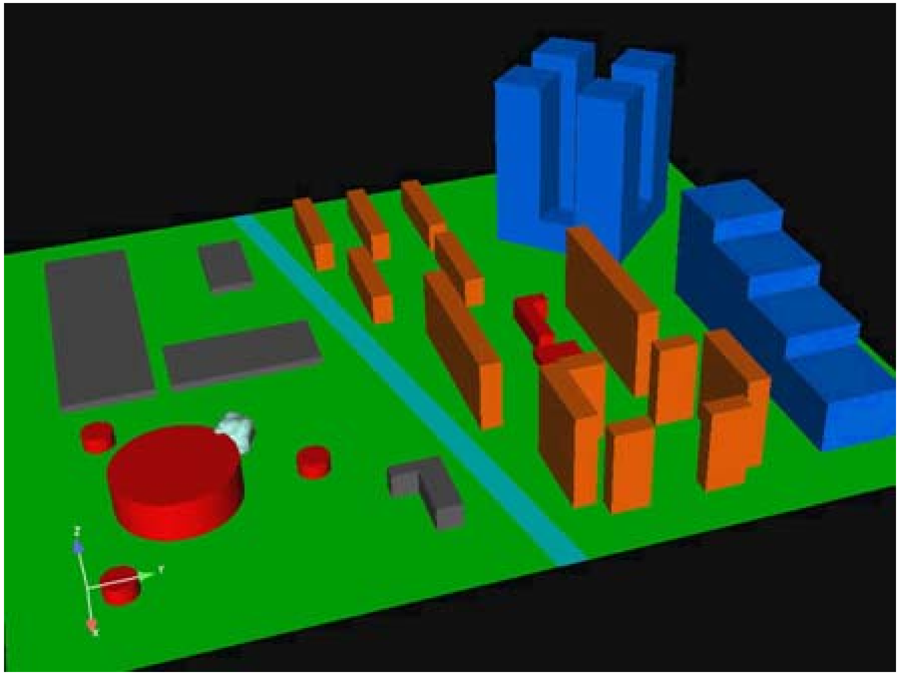


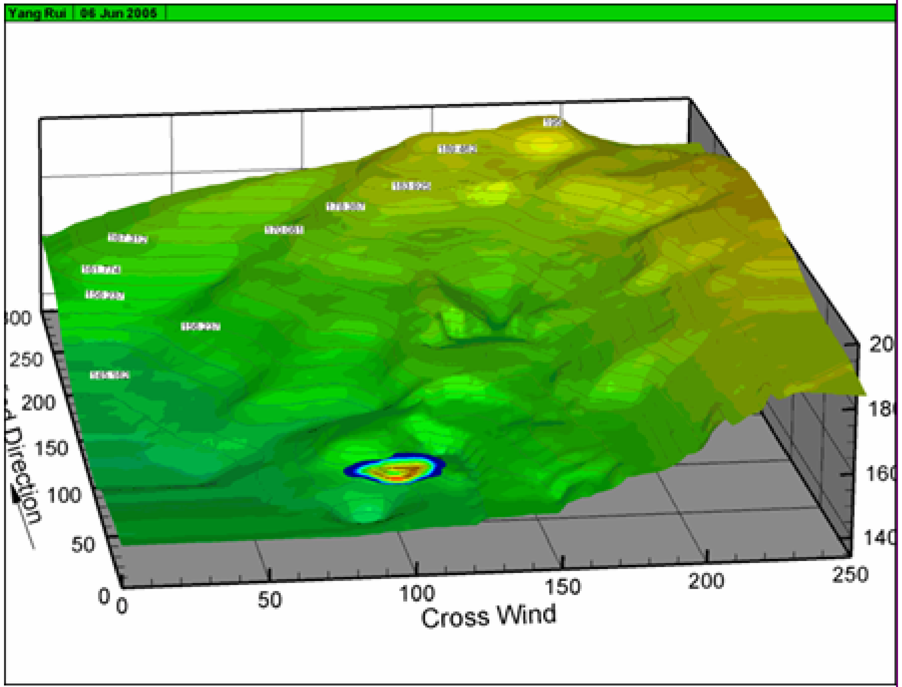
Multi-scale disaster modeling, simulation and alert

- Multi-scale disaster modeling, simulation, and forecasting in emergency response platform



Multi-scale disaster modeling, simulation and alert





Wind speed：3.0m/s Direction：south
Weather：fine Rain：no
Gas： Cl_2 Mol.wt：71

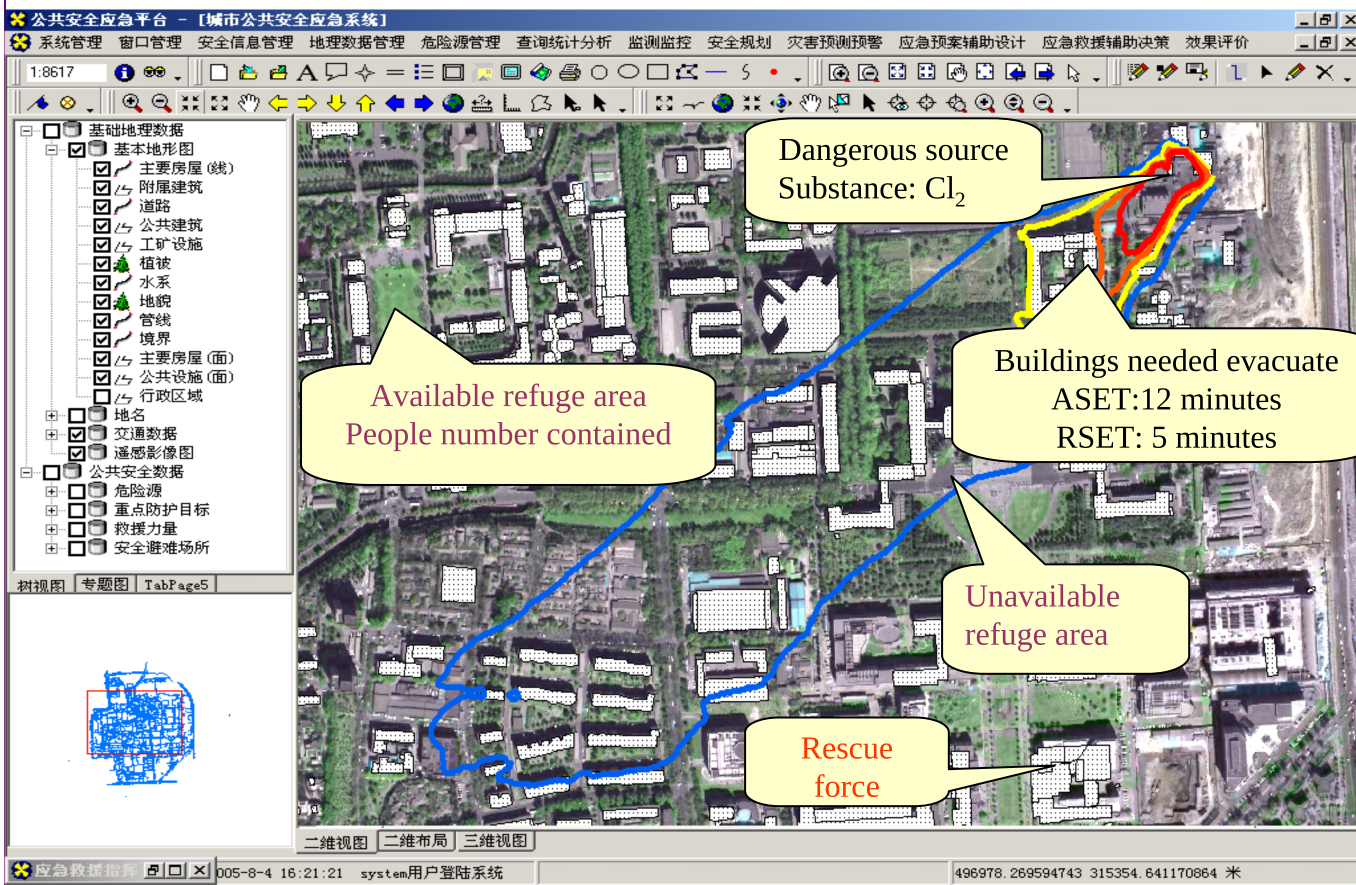
Buildings impact on accident

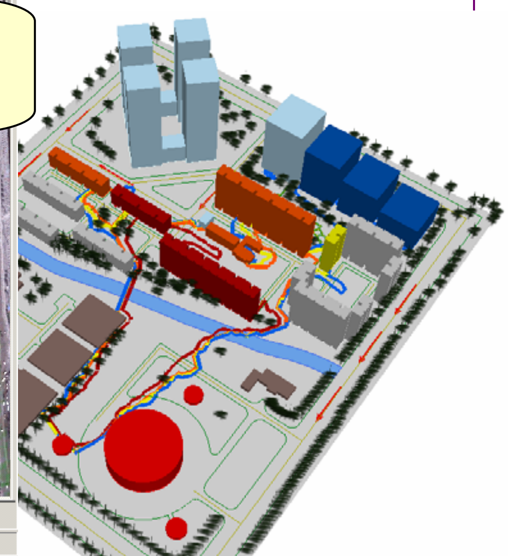
Wind speed：2.0m/s Direction：West
Weather：fine Rain：no
Gas： Cl_2 Mol.wt：71

Topographical impact on accident

Risk assessment and decision-making aid tech.

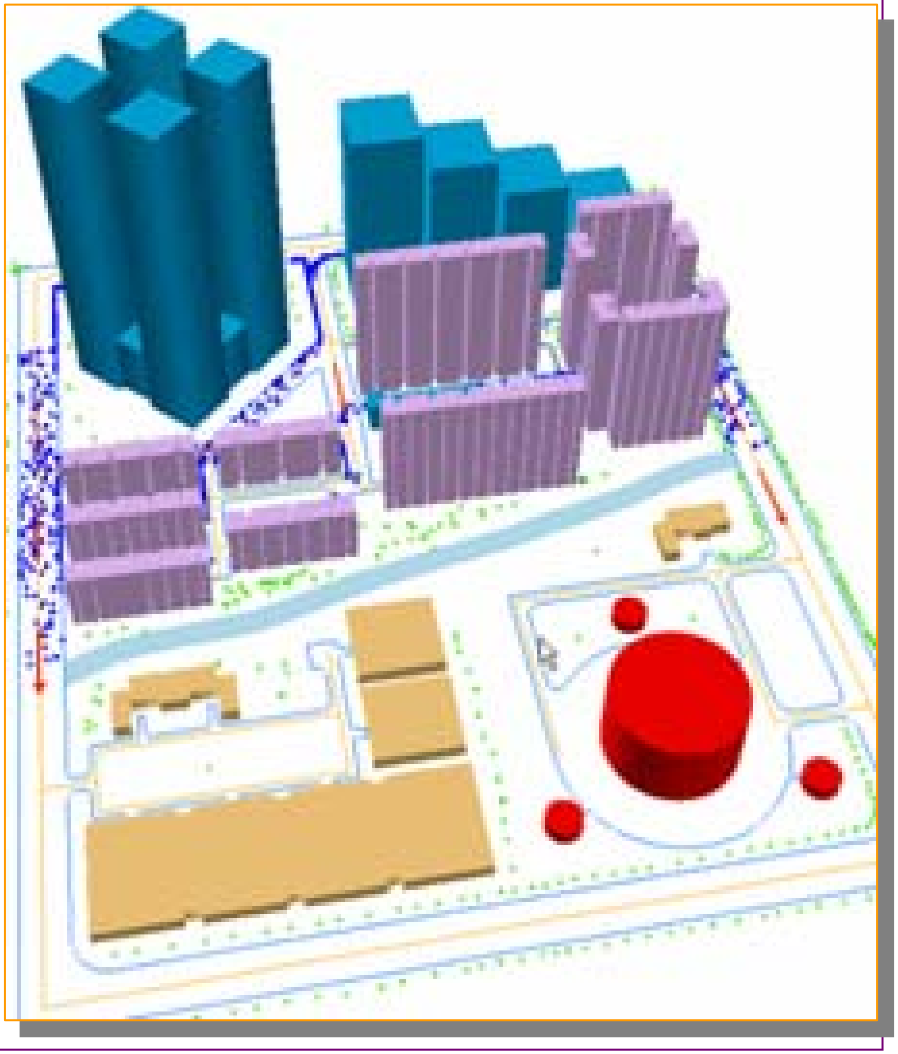
- Advancing risk assessment and decision-making aid systems based on GIS and etc.



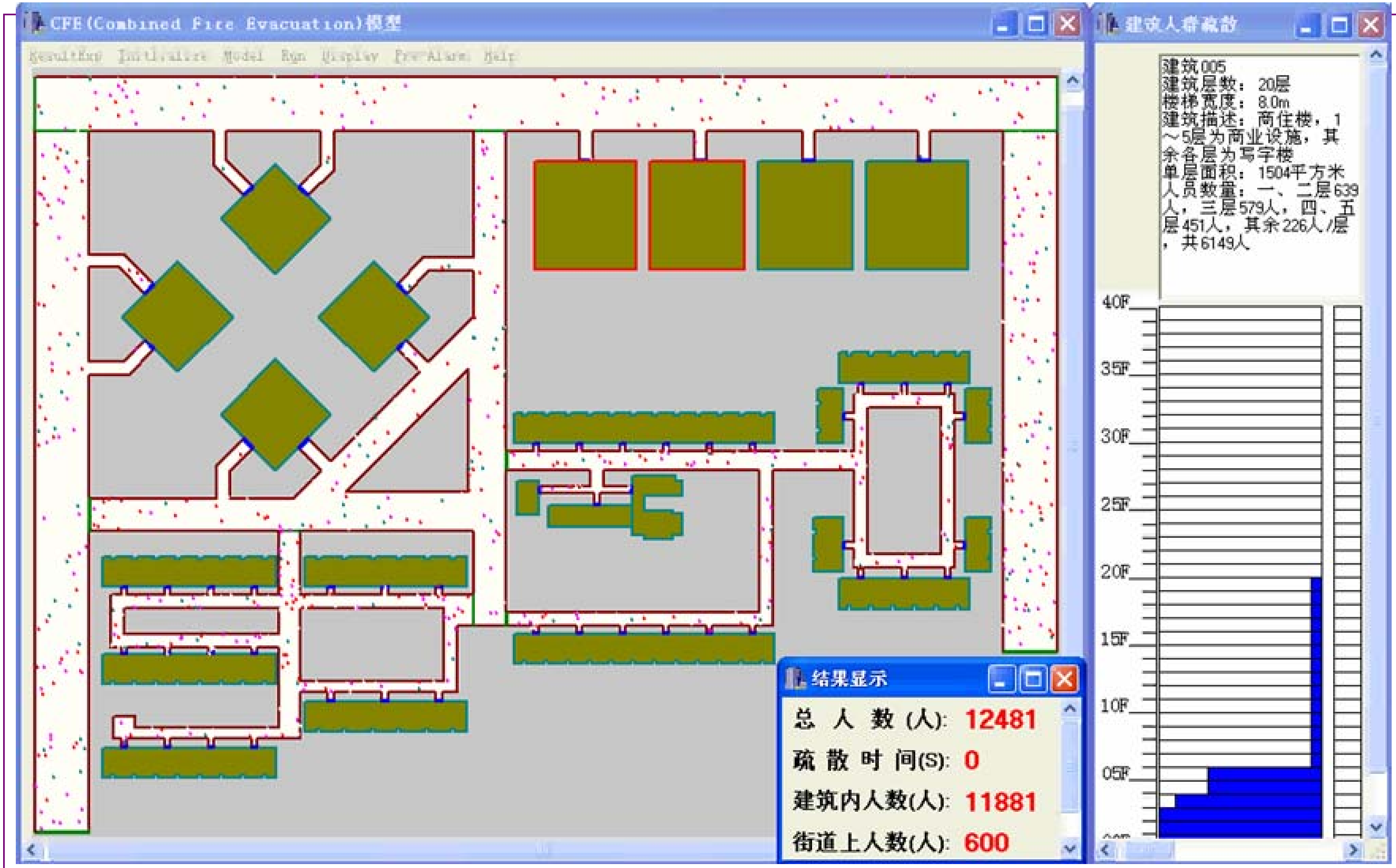


Double nested city evacuation model

- Double nested city evacuation model considering the big region of urban and large quantity of people
- Combined with the prediction of accident development and rescue operation, optimizing the range and route of evacuation.



Double nested city evacuation model



Conclusions

- Fire will continue to be one of the major disasters threatening the life, property and environment.
- There still remains high challenge in revealing the mechanisms and behaviors of fire phenomena as well as developing advanced fire safety technologies.

Conclusions

- Facing the natural and man-made disasters emergency management is one of the crucial factors, which should not only make us safer, but also make our daily lives better.
- Intellectual response platform assembling many existing and new technologies is a powerful tool for optimizing decision on rescue operation.

Conclusions

- Common enemy: natural and man-made disasters.
- Common mission: to protect people and society from the disasters.
- It is important to enhance international exchange and cooperation for fire and public safety research.

Thanks